GPS+ Reference Manual

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Publication Number: OM-20000039
Revision Level: 0I
Revision Date: 2007/07/16

Proprietary Notice

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NovAtel Inc.
Customer Service Department
1120 - 68 Avenue NE
Calgary, AB
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Chapter 1 GPS Overview

The Global Positioning System (GPS) is a satellite navigation system capable of providing a highly accurate, continuous global navigation service independent of other positioning aids. GPS provides 24-hour, all-weather, worldwide coverage with position, velocity and timing information.

The system uses the NAVSTAR (NAVigation Satellite Timing And Ranging) satellites which consists of 24 active satellites to provide a GPS receiver with at least six satellites in view at all times. A minimum of four satellites in view are needed to allow the receiver to compute its current latitude, longitude, altitude with reference to mean sea level and the GPS system time. As of 2007, there are 30 operational satellites.

At the time of publications, the current GPS constellation consists of 29 satellites and the most recent (Block IIR-M) satellite was launched on September 26, 2005. The GPS constellation and individual satellite status is updated every working day by NAVSTAR. See *Chapter 11*, *Standards/References* starting on *Page 50* for their contact information and a link to their website.

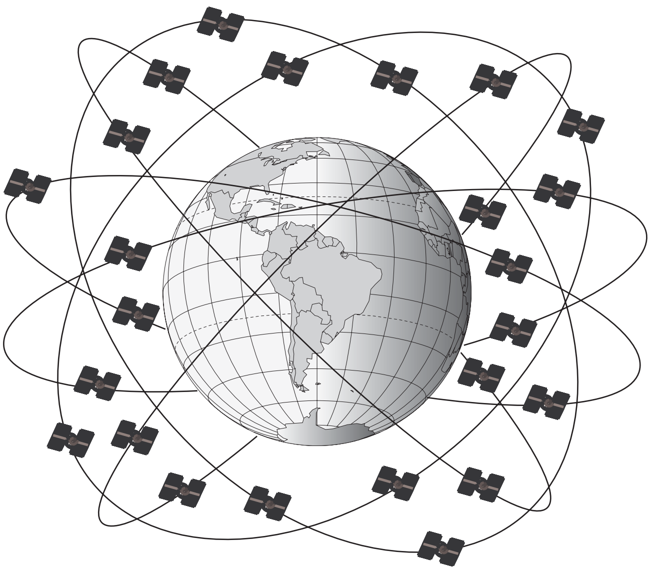


Figure 1: NAVSTAR Satellite Orbit Arrangement

✉ NovAtel Application Notes on the topics covered in this reference manual, and many more, are available from our website at http://www.novatel.com/support/applicationnotes.htm.

1.1 GPS System Design

The GPS system design consists of three parts:

- The Space segment
- The Control segment
- The User segment

All these parts operate together to provide accurate three dimensional positioning, timing and velocity data to users worldwide.

1.1.1 The Space Segment

The space segment is composed of the NAVSTAR GPS satellites. The constellation of the system consists of 24 satellites in six 55° orbital planes, with four satellites in each plane (plus room for spares). The orbit period of each satellite is approximately 12 hours at an altitude of 20 183 kilometers. This provides a GPS receiver with at least six satellites in view from any point on Earth, at any particular time.

The GPS satellite signal identifies the satellite and provides the positioning, timing, ranging data, satellite status and the corrected ephemerides (orbit parameters) of the satellite to the users. The satellites can be identified either by the Space Vehicle Number (SVN) or the Pseudorandom Code Number (PRN). The PRN is used by the NovAtel receiver.

The GPS satellites transmit on several L-band frequencies. L1 is centered at 1575.42 MHz, L2 at 1227.60 MHz and L5 at 1176.45 MHz. The L1 carrier is modulated by the C/A code (Coarse/Acquisition) and the P-code (Precision) which is encrypted for military and other authorized users. The L2 carrier is modulated with the P-code and L2C (civilian) code beginning with the GPS IIR-M satellites. Please see also *Section 9.1* starting on *Page 42*, which includes a sub-section on code and carrier.

1.1.2 The Control Segment

The control segment consists of a master control station, five base stations and three data up-loading stations in locations all around the globe.

The base stations track and monitor the satellites via their broadcast signals. The broadcast signals contain the ephemeris data of the satellites, the ranging signals, the clock data and the almanac data. These signals are passed to the master control station where the ephemerides are re-computed. The resulting ephemerides corrections and timing corrections are transmitted back to the satellites via the data up-loading stations.

1.1.3 The User Segment

The user segment, such as the NovAtel receiver, consists of equipment which tracks and receives the satellite signals. The user equipment must be capable of simultaneously processing the signals from a minimum of four satellites to obtain accurate position, velocity and timing measurements. The NovAtel OEMV receiver can track 14 satellites, which can occur at high latitudes.

1.2 Height Relationships

What is a geoid?

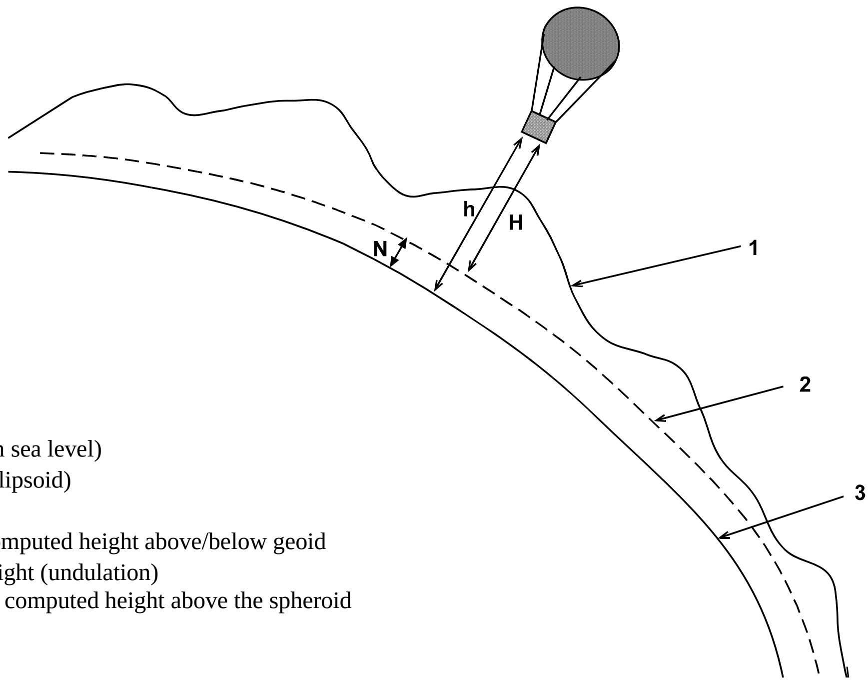
An equipotential surface is any surface where gravity is constant. This surface best represents mean sea level and not only covers the water but is projected throughout the continents. In North America this surface is most commonly used at its zero value, that is, all heights are referenced to this surface.

What is an ellipsoid?

An ellipsoid, also known as a spheroid, is a mathematical surface which is sometimes used to represent the Earth. Whenever you see latitudes and longitudes describing the location, this coordinate is being referenced to a specific ellipsoid. GPS positions are referred to an ellipsoid known as WGS84 or WGS-84 (World Geodetic System of 1984).

What is the relationship between a geoid and an ellipsoid?

The relationship between a geoid and an ellipsoid is shown in *Figure 2, Illustration of Receiver Height Measurements* on *Page 11*.



References:

1 Topography
2 Geoid (mean sea level)
3 Spheroid (ellipsoid)

H = Receiver computed height above/below geoid
N = Geoidal Height (undulation)
h = GPS system computed height above the spheroid
N = h - H

Figure 2: Illustration of Receiver Height Measurements

From the above diagram, and the formula **h = H + N,** to convert heights between the ellipsoid and geoid we require the geoid-ellipsoid separation value. This value is not easy to determine. A world-wide model is generally used to provide these values. NovAtel GPS receivers store this value internally. This model can also be augmented with local height and gravity information. A more

precise geoid model is available from government survey agencies for example, U.S. National Geodetic Survey or Geodetic Survey of Canada (see *Chapter 11, Standards/References* starting on *Page 50*).

Why is this important for GPS users?

The above formula is critical for GPS users as they typically obtain ellipsoid heights and need to convert these into mean sea level heights. Once this conversion is complete, users can relate their GPS derived heights to more “usable” mean sea level heights.

1.3 GPS Positioning

GPS positioning can be categorized as follows:

1. single-point or differential
2. static or kinematic
3. real-time or post-mission data processing

A distinction should be made between *accuracy* and *precision*. *Accuracy* refers to how close an estimate or measurement is to the true but unknown value; *precision* refers to how close an estimate is to the mean (average) estimate. *Figure 3* illustrates various relationships between these two parameters: the true value is "located" at the intersection of the cross-hairs, the centre of the shaded area is the "location" of the mean estimate, and the radius of the shaded area is a measure of the uncertainty contained in the estimate.

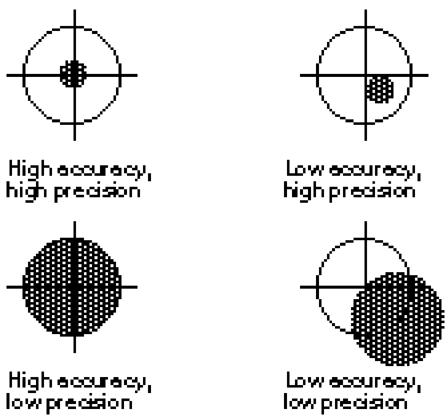


Figure 3: Accuracy versus Precision[1]

1. Environment Canada, 1993, Guideline for the Application of GPS Positioning, p. 22.

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1.3.1 Single-Point vs. Differential Positioning

In *single-point* positioning, coordinates of a GPS receiver at an unknown location are sought with respect to the Earth's reference frame by using the known positions of GPS satellites being tracked. The position solution generated by the receiver is initially developed in Earth-Centered-Earth-Fixed (ECEF) coordinates which can subsequently be converted to any other coordinate system. See *Figure 4* on *Page 13* for a definition of the ECEF coordinates. With as few as four GPS satellites in view, the absolute position of the receiver in three-dimensional space can be determined. Only one receiver is needed.

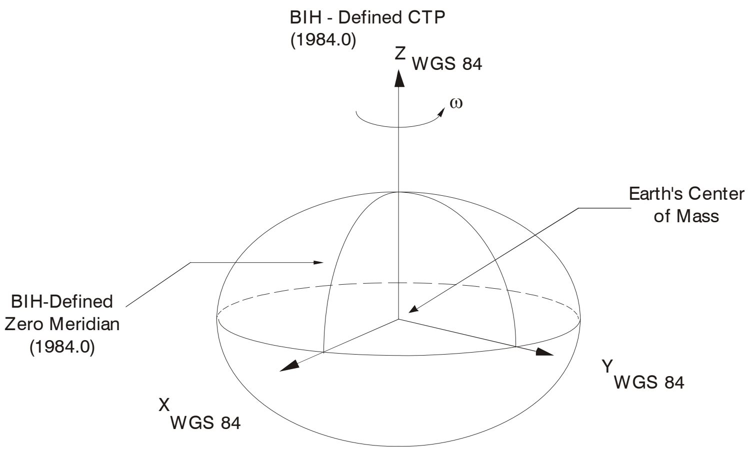
- Definitions - *

Origin = Earth's center of mass

Z-Axis = Parallel to the direction of the Conventional Terrestrial Pole (CTP) for polar motion, as defined by the Bureau International de l'Heure (BIH) on the basis of the coordinates adopted for the BIH stations.

X-Axis = Intersection of the WGS 84 Reference Meridian Plane and the plane of the CTP's Equator, the Reference Meridian being parallel to the Zero Meridian defined by the BIH on the basis of the coordinates adopted for the BIH stations.

Y-Axis = Completes a right-handed, earth-centered, earth-fixed (ECEF) orthogonal coordinate system, measured in the plane of the CTP Equator, 90° East of the X-Axis.



* Analogous to the BIH Defined Conventional Terrestrial System (CTS), or BTS, 1984.0.

Figure 4: The WGS84 ECEF Coordinate System

In *differential* positioning, also known as *relative* positioning, the coordinates of a GPS receiver at an unknown point (the “rover” station) are sought with respect to a GPS receiver at a known point (the “base” station). The concept is illustrated in *Figure 5, Example Differential Positioning Setup* on *Page 14.* The differential-position accuracy of two receivers locked on the same satellites and not far

removed from each other - up to tens of kilometers - is extremely high. The largest error contributors in single-point positioning are those associated with atmospheric-induced effects. These errors, however, are highly correlated for adjacent receivers and hence cancel out in differential measurements. Since the position of the base station can be determined to a high degree of accuracy using conventional surveying techniques, any differences between its known position and the position computed using GPS techniques can be attributed to various components of error as well as the receiver's clock bias. Once the estimated clock bias is removed, the remaining error on each pseudorange can be determined. The base station sends information about each satellite to the rover station, which in turn can determine its position much more exactly than would be possible otherwise.

The advantage of differential positioning is that much greater precision (presently as low as 2 mm, depending on the method and environment) can be achieved than by single-point positioning. In order for the observations of the base station to be integrated with those of the rover station, differential positioning requires either a data link between the two stations (if the positioning is to be achieved in real-time) or else post-processing of the data collected by the rover station. At least four GPS satellites in view are still required. The absolute accuracy of the rover station's computed position will depend on the accuracy of the base station's position.

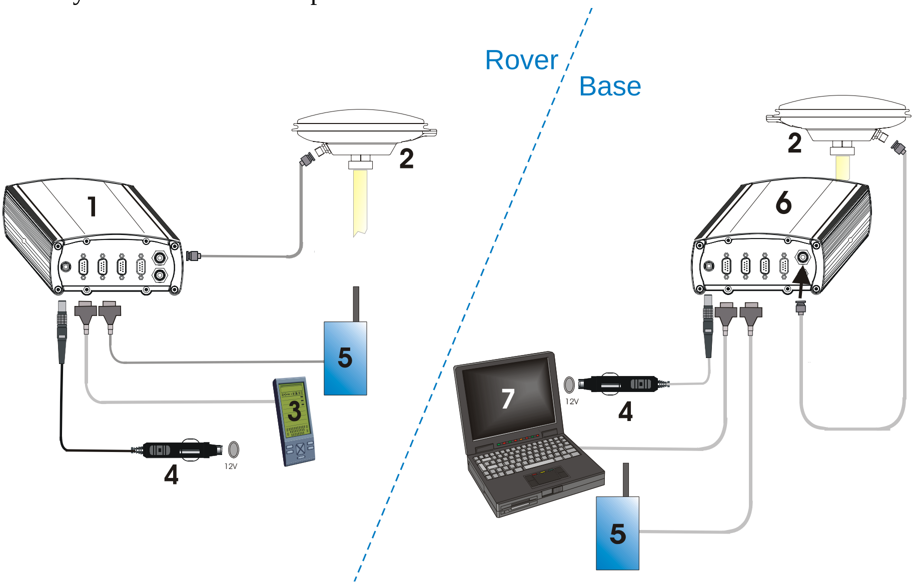


Figure 5: Example Differential Positioning Setup

Reference	Description
1	A ProPak-V3 receiver for the rover station
2	User-supplied NovAtel GNSS antenna
3	User-supplied data storage device to COM1
4	User-supplied power supply
5	User-supplied radio device to COM2
6	A ProPak-V3 receiver for the base station
7	User-supplied laptop/PC, for setting up and monitoring, to COM1

1.3.2 Static vs. Kinematic Positioning

Static and *kinematic positioning* refer to whether a GPS receiver is stationary or in motion while collecting GPS data. Refer to *Chapter 5* of the *OEMV Family Installation and Operation Manual* for more details on static and kinematic positioning. SUPERSTAR-II and OEM4-based product manuals also contain a chapter on positioning modes of operation. Portable Document Format (PDF) manuals are available from our website at http://www.novatel.com/support/docupdates.htm.

1.3.3 Real-time vs. Post-mission Data Processing

Real-time or *post-mission* data processing refer to whether the GPS data collected by the receiver is processed as it is received or after the entire data-collection session is complete. Refer to *Chapter 5* of the *OEMV Family Installation and Operation Manual* set for more details on post-processed and real-time positioning.

OEMV-based output is compatible with post-processing software from the Waypoint Products Group, NovAtel Inc. See also our website at www.novatel.com for details.

1.3.4 Performance Considerations

1.3.4.1 Antenna Selection

An active antenna is required because its Low-Noise Amplifier (LNA) boosts the power of the incoming signal to compensate for the line loss between the antenna and the receiver.

NovAtel offers a variety of single and dual-frequency GNSS antenna models, as indicated in *Table 1* below. All include band-pass filtering and an LNA. The GNSS antenna you choose will depend on your particular application. Each of these models offer exceptional phase-center stability as well as a significant measure of immunity against multipath interference. Each one has an environmentally-sealed radome. The ANT-532, ANT-533, ANT-534, ANT-536, ANT-537, ANT-538, GPS-702L, GPS-701GG and GPS-702GG are RoHS compliant.

Table 1: NovAtel GNSS Antenna Models

Models	Frequencies Supported	GPS	GLONASS
701, 511, 521, 536, 537	L1 only	✓	✗
702, 532, 533	L1 and L2	✓	✗
702L, 534	L1 and L2 plus L-band	✓	✗
701GGL, 538	L1 plus L-band	✓	✓
701GG	L1 only	✓	✓
702GGL	L1 and L2 plus L-band	✓	✓
702-GG	L1 and L2	✓	✓

1.3.4.2 Cable Length

An appropriate coaxial cable is one that is matched to the impedance of the antenna and receiver being used (50 ohms), and whose line loss does not exceed 10.0 dB. If the limit is exceeded, excessive signal degradation will occur and the receiver may not be able to meet its performance specifications. NovAtel offers a variety of coaxial cables to meet your GPS antenna interconnection requirements.

Note that a conversion is required between the female MMCX connector on a bare OEMV card and the female TNC connector on NovAtel's GNSS antennas. Your local NovAtel dealer can advise you about your specific configuration. If your application requires the use of cable longer than 30 m, refer to the application note *RF Equipment Selection and Installation* on our website at http://www.novatel.com/support/applicationnotes.htm, or you can obtain it directly from NovAtel Customer Service.

High-quality coaxial cables should be used because a mismatch in impedance, possible with lower quality cable, produces reflections in the cable that increase signal loss. Though it is possible to use other high-quality antenna cables, the performance specifications of NovAtel receivers are warranted only when used with NovAtel-supplied accessories.

1.3.4.3 GNSS System Errors

In general, GPS SPS C/A code single-point pseudorange positioning systems are capable of absolute position accuracies of about 1.8 meters or less. This level of accuracy is really only an estimation, and may vary widely depending on numerous GNSS system biases, environmental conditions, as well as the GNSS receiver design and engineering quality.

There are numerous factors which influence the single-point position accuracies of any GNSS code receiving system. As the following list shows, a receiver's performance can vary widely when under the influences of these combined system and environmental biases.

- Ionospheric Delays — The Earth's ionospheric layers cause varying degrees of GNSS signal propagation delay. Ionization levels tend to be highest during daylight hours causing propagation delay errors of up to 30 meters, whereas night time levels are much lower and may be as low as 6 meters.
- Tropospheric Delays — The Earth's tropospheric layer causes GNSS signal propagation delays. The amount of delay is at the minimum (about three metres) for satellite signals arriving from 90 degrees above the horizon (overhead), and progressively increases as the angle above the horizon is reduced to zero where delay errors may be as much as 50 metres at the horizon.
- Ephemeris Errors — Some degree of error always exists between the broadcast ephemeris' predicted satellite position and the actual orbit position of the satellites. These errors directly affect the accuracy of the range measurement.
- Satellite Clock Errors — Some degree of error also exists between the actual satellite clock time and the clock time predicted by the broadcast data. This broadcast time error causes some bias to the pseudorange measurements.
- Receiver Clock Errors — Receiver clock error is the time difference between GPS receiver time and true GPS Time. All GNSS receivers have differing clock offsets from GPS Time that vary from receiver to receiver by an unknown amount depending on the oscillator type and quality (TCXO versus OCXO, and

so on). However, because a receiver makes all of its single-point pseudorange measurements using the same common clock oscillator, all measurements are equally offset, and this offset can generally be modeled or quite accurately estimated to effectively cancel the receiver clock offset bias. Thus, in single-point positioning, receiver clock offset is not a significant problem.

- Multipath — Multipath signal reception can potentially cause large pseudorange and carrier phase measurement biases. Multipath conditions are very much a function of specific antenna site location versus local geography and man-made structural influences. Severe multipath conditions could skew range measurements by as much as 100 meters or more. See also *Chapter 9, Multipath* starting on *Page 41*.

1.3.4.4 RTK

When referring to the "performance" of RTK software, two factors are introduced: baseline length and convergence time.

Baseline Length

Baseline length: the position estimate becomes less precise as the baseline length increases. Note that the baseline length is the distance between the phase centres of the two antennas. Identifying the exact position of your antenna's phase centre is essential; this information is typically supplied by the antenna's manufacturer or vendor.

The RTK software automatically makes the transition between short and longer baselines, but the best results are obtained for baselines less than 10 km. The following are factors which are related to baseline length:

- ephemeris errors — These produce typical position errors of 0.75 cm per 10 km of baseline length.
- ionospheric effects — The dominant error for single-frequency GPS receivers on baselines exceeding 10 km. Differential ionospheric effects reach their peak at around 2 pm local time, being at a minimum during hours of darkness. Ionospheric effects can be estimated and removed on dual-frequency GPS receivers, greatly increasing the permissible baseline length, but at the cost of introducing additional "noise" to the solution. Therefore, this type of compensation is only used in cases where the ionospheric error is much larger than the noise and multipath error.
- tropospheric effects — These produce typical position errors of approximately 1 cm per 10 km of baseline length. This error increases if there is a significant height difference between the base and rover stations, as well as if there are significantly different weather conditions between the two sites.

A related issue is that of multipath interference, the dominant error on short differential baselines. Generally, multipath can be reduced by choosing the antenna's location with care, and by the use of a GPS-700 family antenna (no need for a choke ring) or a L1/L2 antenna and a choke ring antenna ground plane. See also *Table 1* on *Page 15* and *Chapter 9, Multipath* starting on *Page 41*.

Convergence Time

The position estimate becomes more accurate and more precise with time. However, convergence time is dependent upon baseline length: while good results are available after a minute or so for short baselines, the time required increases with baseline length. Convergence time is also affected by the number of satellites which can be used in the solution (the more satellites, the faster the convergence) and by the errors listed in *Baseline Length* above.

Chapter 2 SPAN Inertial Navigation Overview

GPS positioning observes range measurements from orbiting Global Positioning System Satellites. From these observations, the receiver can compute position and velocity with high accuracy. NovAtel GPS positioning systems have been established as highly accurate positioning tools, however GPS in general has some significant restrictions, which limit its usefulness in some situations. Accurate GPS positioning requires line of site view to at least four satellites simultaneously. If these criteria are met, differential GPS positioning can be accurate to within a few centimetres. If however, some or all of the satellite signals are blocked, the accuracy of the position reported by GPS degrades substantially, or may not be available at all.

In general, an Inertial Navigation System (INS) uses forces and rotations measured by an IMU to calculate acceleration, velocity and attitude. This capability is embedded in the firmware of our *plus* and OEMV series of receivers. Forces are measured by accelerometers in three perpendicular axes within the IMU and the gyros measure rotations around those axes. Over short periods of time, inertial navigation gives very accurate acceleration, velocity and attitude output. Since the IMU sensor measures changes in orientation and acceleration, the INS determines changes in position and attitude. The IMU must have prior knowledge of its initial position, initial velocity, initial attitude, Earth rotation rate and gravity field. Once these parameters are known, an INS is capable of providing an autonomous solution with no external inputs. However, because of errors in the IMU sensor measurements that accumulate over time, an inertial-only solution will degrade with time unless external updates such as position, velocity or attitude are supplied.

NovAtel's SPAN system's combined GPS/INS solution integrates the raw inertial measurements with all available GPS solution and raw measurement information to provide the optimum solution possible in any situation. By using the high accuracy of the GPS solution, the INS measurement errors can be modeled and mitigated. Conversely, the continuity and relative accuracy of the INS solution enables faster GPS signal re-acquisition and RTK solution convergence.

The advantages of using SPAN technology are its ability to:

- Provide a full attitude solution (roll, pitch and azimuth)
- Provide continuous solution output (in situations when a GPS-only solution is impossible)
- Provide faster signal re-acquisition and RTK solution resolution (over stand-alone GPS because of the tightly integrated GPS and IMU observations)
- Output high-rate (up to 100 Hz) position, velocity and attitude solutions for high-dynamic applications
- Use raw phase observation data (to constrain INS solution drift even when too few satellites are available for a full GPS solution)

✉ Refer to the *SPAN Technology User Manual* available from our website at:

http://www.novatel.com/support/docupdates.htm.

Chapter 3 Satellite-Based Augmentation System

A Satellite-Based Augmentation System (SBAS) is a type of geo-stationary satellite system that improves the accuracy, integrity, and availability of the basic GPS signals. Accuracy is enhanced through the use of wide area corrections for GPS satellite orbits and ionospheric errors. Integrity is enhanced by the SBAS network quickly detecting satellite signal errors and sending alerts to receivers to not use the failed satellite. Availability is improved by providing an additional ranging signal to each SBAS geo-stationary satellite.

SBAS includes the Wide-Area Augmentation System (WAAS), the European Geo-Stationary Navigation System (EGNOS), and the MTSAT Satellite-Based Augmentation System (MSAS). The Chinese SNAS, Indian GAGAN and Australian GRAS systems are in progress. At the time of publication, there are two WAAS satellites over the Pacific Ocean (PRN 135 and PRN 138), an EGNOS satellite over the eastern Atlantic Ocean (PRN 120), an EGNOS satellite over the Indian Ocean (PRN 126) and another EGNOS GEO satellite over the African mid-continent (PRN 124). SBAS data is available from any of these satellites and more satellites will be available in the future.

✉ Since July, 2003, WAAS has been certified for Class 1/ Class 2 civilian aircraft navigation.

Figure 6 [1] shows the regions applicable to each SBAS system mentioned in the paragraph above and how NovAtel is involved in each of them.

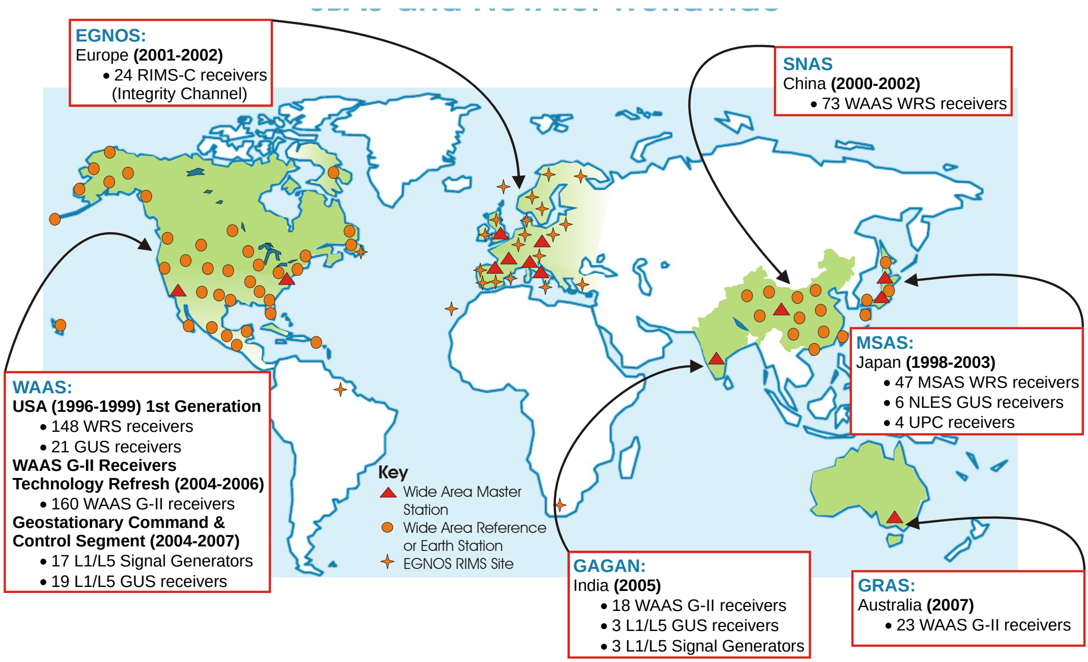


Figure 6: SBAS and NovAtel

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1. Last updated in August, 2007.

SBAS is made up of a series of Reference Stations, Master Stations, Ground Uplink Stations and Geostationary Satellites (GEOs), see *Figure 7, The SBAS Concept* on *Page 22*. The Reference Stations, which are geographically distributed, pick up GPS satellite data and route it to the Master Stations where wide area corrections are generated. These corrections are sent to the Ground Uplink Stations which up-link them to the GEOs for re-transmission on the GPS L1 frequency. These GEOs transmit signals which carry accuracy and integrity messages, and which also provide additional ranging signals for added availability, continuity and accuracy. These GEO signals are available over a wide area and can be received and processed by NovAtel receivers with appropriate firmware. GPS user receivers are thus able to receive SBAS data in-band and use not only differential corrections, but also integrity, residual errors and ionospheric information for each monitored satellite.

The signal broadcast via the SBAS GEOs to the SBAS users is designed to minimize modifications to standard GPS receivers. As such, the GPS L1 frequency (1575.42 MHz) is used, together with GPS-type modulation, for example, a Coarse/Acquisition (C/A) pseudorandom (PRN) code. In addition, the code phase timing is maintained close to GPS Time to provide a ranging capability.

The primary functions of SBAS include:

- data collection
- determining ionospheric corrections
- determining satellite orbits
- determining satellite clock corrections
- determining satellite integrity
- independent data verification
- SBAS message broadcast and ranging
- system operations & maintenance

3.1 SBAS Receiver

All OEMV models, many OEM4 and several SSII models of NovAtel receivers are equipped with SBAS capability. The ability to incorporate the SBAS corrections into the position is available in these models.

SBAS data can be output in log format and can incorporate these corrections to generate differential-quality position solutions. Standard SBAS data messages are analyzed based on RTCA standards for GPS/WAAS airborne equipment. Please refer to your *SUPERSTAR II Firmware Reference Manual* or *OEMV Firmware Reference Manual* for details on SBAS commands and logs.

An SBAS-capable receiver permits anyone within the area of coverage to take advantage of its benefits with no subscription fee.

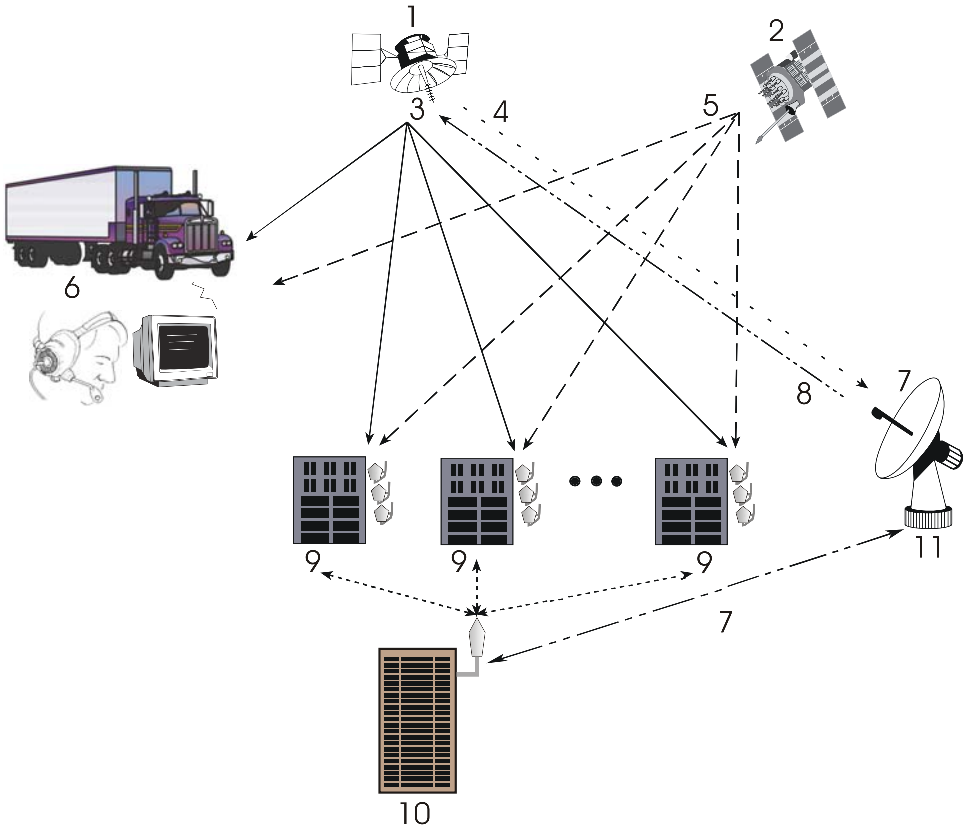

Figure 7: The SBAS Concept

Reference	Description	Reference	Description
1	Geo-stationary Satellite (GEO)	8	C-Band
2	GPS Satellite Constellation	9	SBAS Reference Station
3	L1	10	SBAS Master Station
4	L1 and C-Band	11	Ground Uplink Station
5	L1 and L2		
6	GPS User		
7	Integrity data, differential corrections and ranging control		

Chapter 4 L-band Positioning

The transmission of OmniSTAR or Canada-Wide Differential Global Positioning System (CDGPS) corrections are from geo-stationary satellites. The L-band frequency of these geo-stationary satellites is sufficiently close to that of GPS that a common, single antenna, such as the NovAtel 702L, may be used.

Both systems are portable and capable of sub-meter accuracy over their coverage areas. See *Figure 8*.

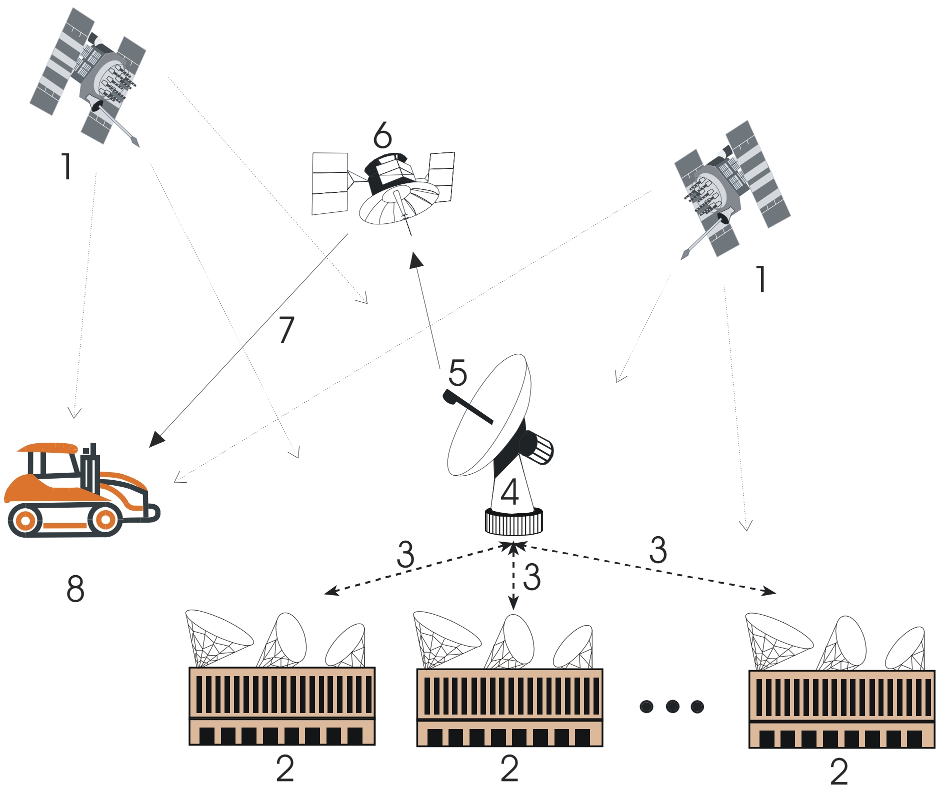

Figure 8: L-band Concept

Reference	Description
1	GPS satellites
2	Multiple L-band ground stations
3	Send GPS corrections to 4
4	Network Control Center where data corrections are checked and repackaged for uplink to 6
5	DGPS uplink
6	L-band geo-stationary satellite
7	L-band DGPS signal
8	Correction data are received and applied real-time

The OmniSTAR system is designed for coverage of most of the world's land areas. A subscription charge by geographic area is required. The CDGPS system is a free Canada-wide DGPS service that is accessible coast-to-coast, throughout most of the continental United States, and into the Arctic.

By default the OEMV-1, OEMV-3 and ProPak-V3 models with L-band software support the standard CDGPS sub-meter L1/L2 service and the OmniSTAR Virtual Base Station (VBS) sub-meter L1 service. The OmniSTAR VBS service is upgradeable on the OEMV-3 and ProPak-V3 to the Extra Performance (XP) decimeter L1/L2 service or High Performance (HP) sub-decimeter L1/L2 service via a coded message from an OmniSTAR satellite.

4.1 Coverage

The two systems provide different coverage areas:

- OmniSTAR - Most of the World's Land Areas
- CDGPS - Canada/America-Wide

4.1.1 OmniSTAR Geographic Areas

In most world areas, a single satellite is used by OmniSTAR to provide coverage over an entire continent - or at least very large geographic areas. In North America, a single satellite is used, but it needs three separate beams to cover the continent. The three beams are arranged to cover the East, Central, and Western portions of North America. The same data is broadcast over all three beams, but the user system must select the proper beam frequency. The beams have overlaps of several hundred miles, so the point where the frequency must be changed is not critical.

The L-band frequency can be changed using the ASSIGNLBAND command. Refer to the *OEMV Family Firmware Reference Manual* or to *Volume 2* of the *OEM4 User Manual* set.

The North American OmniSTAR Network currently consists of ten permanent base stations in the Continental U.S., plus one in Mexico. These eleven stations track all GPS satellites above 5 degrees elevation and compute corrections every 600 milliseconds. The corrections are sent to the OmniSTAR Network Control Center (NCC) in Houston via wire networks. At the NCC these messages are checked, compressed, and formed into packets for transmission up to the OmniSTAR satellite transponder. This occurs approximately every few seconds. A packet will contain the latest corrections from each of the North American base stations.

All of the eastern Canadian Provinces, the Caribbean Islands, Central America (south of Mexico), and South America is covered by a single satellite (AM-Sat). A single subscription is available for all the areas covered by this satellite.

OmniSTAR currently has several high-powered satellites in use around the world. They provide coverage for most of the world's land areas. Subscriptions are sold by geographic area. Any Regional OmniSTAR service center can sell and activate subscriptions for any area. They may be arranged prior to travelling to a new area, or after arrival. Contact OmniSTAR at www.omnistar.com for further details.[1]

1. Please see *Page 52* for more OmniSTAR contact information.

4.1.2 Canada/America-Wide CDGPS

In order to enable CDGPS positioning, you must set the L-band frequency for the geographically appropriate CDGPS signal using the ASSIGNLBAND command. Refer to the *OEMV Family Firmware Reference Manual* or to *Volume 2* of the *OEM4 User Manual* set.

The CDGPS signal is broadcast on 4 different spot beams on the MSAT-1 satellite. Depending on your geographic location, there will be a different frequency for the CDGPS signal as shown in *Figure 9*.

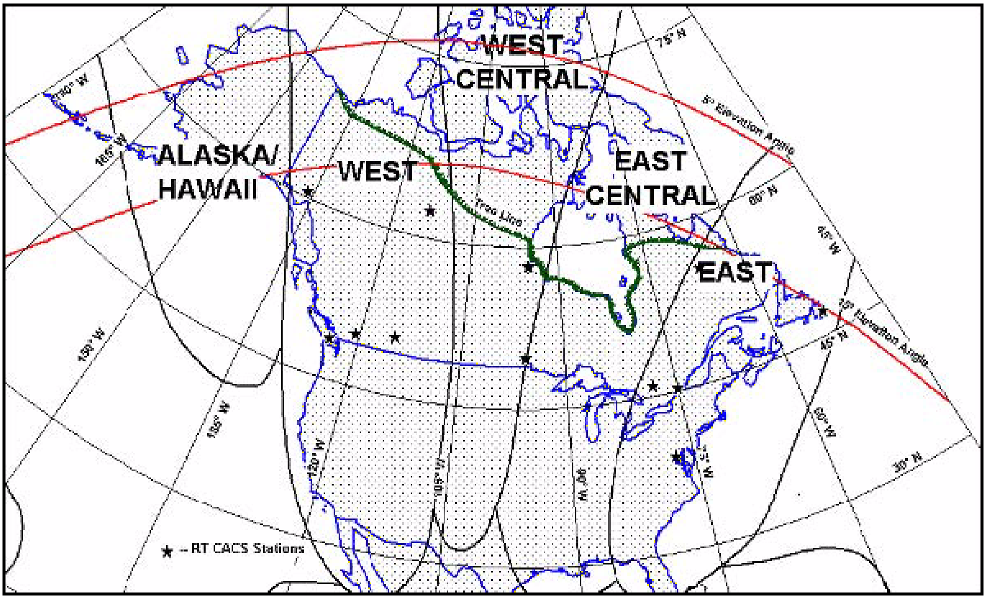

Figure 9: CDGPS Frequency Beams

The following are the spot beam names and their frequencies (in KHz or Hz):

East	1547646 or 1547646000
East-Central	1557897 or 1557897000
West-Central	1557571 or 1557571000
West	1547547 or 1547547000

✉ The CDGPS service does not include the MSAT Alaska/Hawaii beam shown in *Figure 9*.

The data signal is structured to perform well in difficult, or foliated conditions, so the service is available more consistently than other services and has a high degree of service reliability.

CDGPS features wide area technology, possible spatial integrity with all Government of Canada maps and surveys [1 2], 24-hour/7 days-a-week built-in network redundancies and an openly published broadcast protocol.

1. If the coordinates are output using the CSRS datum. Refer to the DATUM command in the *OEMV Family Firmware Reference Manual*.
2. The Geological Survey of Canada website is at http://gsc.nrcan.gc.ca/index_e.php.

4.1.2.1 CDGPS Coverage

Figure 10, CDGPS Percentage (%) Coverage Map as of June 6, 2007 below is a conservative map of the coverage areas that CDGPS[1] guarantees. The coverage may be better in your area.

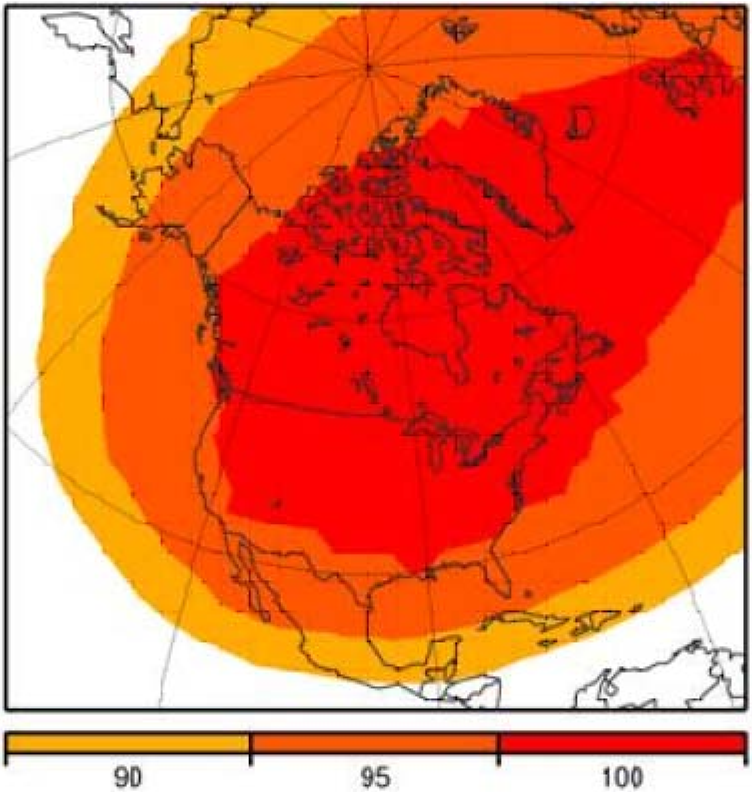

Figure 10: CDGPS Percentage (%) Coverage Map as of June 6, 2007

In *Figure 10*, 100% coverage means that a correction is received for every visible satellite (at or above 10 degrees). 90% coverage means that a correction is received for 90% of visible satellites. For example, if a user views 10 satellites but has 90% coverage then there are no corrections available for one of the satellites. In that case, our firmware shows that a correction is missing for that SV and excludes it from the position calculation.

4.1.2.2 Performance

For the OEMV Family, CDGPS position accuracy is 0.7 m circular error probable (CEP)[2]. Refer also to the *Performance* section of the *Technical Specifications* appendix in the *OEMV Family Installation and Operation User Manual*.

1. Please see *Page 52* for CDGPS contact information.
2. CEP: The radius of a circle such that 50% of a set of events occur inside the boundary.

4.2 L-band Service Levels

Two levels of service are available:

Standard	-	Sub-meter accuracy from OmniSTAR VBS (subscription required) and CDGPS
Extra Performance	-	Decimeter accuracy from OmniSTAR XP (subscription required)
High Performance	-	Sub-decimeter accuracy from OmniSTAR HP (subscription required)

4.2.1 *Standard Service*

The OmniSTAR VBS service uses multiple GPS base stations in a solution and reduces errors due to the GPS signals travelling through the atmosphere. It uses a wide area DGPS solution (WADGPS) and data from a relatively small number of base stations to provide consistent accuracy over large areas. A unique method of solving for atmospheric delays and weighting of distant base stations achieves sub-meter capability over the entire coverage area - regardless of your location relative to any base station.

CDGPS is able to simultaneously track two satellites, and incorporate the corrections into the position. The output is SBAS-like (see WAAS32-WAAS45 in the *OEMV Family Firmware Reference Manual*), and can incorporate these corrections to generate differential-quality position solutions. CDGPS allows anyone within the area of coverage to take advantage of its benefits.

CDGPS and OmniSTAR VBS services are available on OEMV-1 and OEMV-3-based products. NovAtel's ProPak-V3 provides GPS with L-band corrections in one unit, using a common antenna. This means that, with CDGPS or a subscription to the OmniSTAR VBS service, the ProPak-V3 is a high quality receiver with sub-meter capabilities.

The position from the GPSCard in the receiver is used as the L-band system's first approximation. After the L-band processor has taken care of the atmospheric corrections, it then uses its location versus the base station locations, in an inverse distance-weighted least-squares solution. L-band technology generates corrections optimized for the location. It is this technique that enables the L-band receiver to operate independently and consistently over the entire coverage area without regard to where it is in relation to the base stations.

4.2.2 *High and Extra Performance Services*

The OEMV-3 or ProPak-V3 with OmniSTAR High Performance (HP) service gives you more accuracy than the OmniSTAR VBS or CDGPS services. OmniSTAR HP computes corrections in dual-frequency RTK float mode (within about 10 cm accuracy). The XP service is similar to HP but less accurate (15 cm) and more accurate than VBS (1 m). HP uses reference stations while XP uses clock model data from NASA's Jet Propulsion Laboratory (JPL). To obtain these corrections, your receiver must have an HP or XP subscription from OmniSTAR, visit www.omnistar.com for details.

1. For optimal performance, allow the OmniSTAR HP or XP solution to converge prior to starting any dynamic operation.
2. OmniSTAR XP is now available over a wider coverage area.

4.3 L-band Commands and Logs

The ASSIGNLBAND command allows you to set OmniSTAR or CDGPS base station communication parameters. It should include relevant frequency and data rate, for example:

```
assignlband omnistar 1536782 1200
```

or,

```
assignlband cdgps 1547547 4800
```

The PSRDIFFSOURCE command lets you identify from which source to accept RTCA1, RTCM1, CDGPS or OmniSTAR VBS differential corrections. For example, in the PSRDIFFSOURCE command, OMNISTAR enables OmniSTAR VBS and disables other DGPS types. AUTO means the first received RTCM or RTCA message has preference over an OmniSTAR VBS or CDGPS message.

The RTKSOURCE command lets you identify from which source to accept RTK (RTCM, RTCMV3, RTCA, CMR, CMRPLUS and OmniSTAR HP or XP) differential corrections. For example, in the RTKSOURCE command, OMNISTAR enables OmniSTAR HP or XP, if allowed, and disables other RTK types. AUTO means the NovAtel RTK filter is enabled and the first received RTCM, RTCA or CMR message is selected and the OmniSTAR HP or XP message, if allowed, is enabled. The position with the best standard deviation is used in the BESTPOS log.

The HPSEED command allows you to specify the initial position for OmniSTAR HP.

The HPSTATICINIT command allows you to speed up the convergence time of the HP or XP process when you are not moving.

The PSRDIFFSOURCE and RTKSOURCE commands are useful when the receiver is receiving corrections from multiple sources.

Several L-band specific logs also exist and are prefixed by the letters RAWLBAND, LBAND or OMNI. CDGPS corrections are output similarly to SBAS corrections. There are four SBAS fast corrections logs (WAAS32-WAAS35) and one slow corrections log (WAAS45) for CDGPS. The CDGPS PRN is 209.

☒ 1. In addition to a NovAtel receiver with L-band capability, a subscription to the OmniSTAR, or use of the free CDGPS, service is required.

2. All PSRDIFFSOURCE entries fall back to SBAS (even NONE) for backwards compatibility.

Refer to the *OEMV Family Firmware Reference Manual* for more details on individual L-band commands and logs.

Chapter 5 GLONASS Overview

The OEMV-1G-based, OEMV-2-based, and OEMV-3-based products are GLONASS-enabled with full code and carrier phase (RTK) positioning, as well as the ability to record raw GPS and GLONASS measurements. We discuss these capabilities further in this overview.[1]

RTK performs significantly better when tracking both GPS and GLONASS satellites, than when tracking GPS satellites only. Adding GLONASS to GPS improves all aspects of satellite navigation and RTK operation (availability, reliability, stability, time of RTK initialization, and so on).

The use of GLONASS in addition to GPS provides very significant advantages:

- increased satellite signal observations
- markedly increased spatial distribution of visible satellites
- reduced Horizontal and Vertical Dilution of Precision factors
- decreased occupation times means faster RTK results

In order to determine a position in GPS-only mode the receiver must track a minimum of four satellites, representing the four unknowns of 3-D position and time. In combined GPS/GLONASS mode, the receiver must track five satellites, representing the same four previous unknowns and at least one GLONASS satellite to determine the GPS/GLONASS time offset.

With the availability of combined GPS/GLONASS receivers, users have access to a potential 48+ satellite-combined system. With 48+ satellites, performance in urban canyons and other locations with restricted visibility, such as forested areas improves as more satellites are visible in the non-blocked portions of the sky. A larger satellite constellation also improves real-time carrier phase differential positioning performance.

Russia has committed itself to bringing the system up to the required minimum of 18 active satellites by the end of 2007, and signed an agreement with India that provides for the launches of GLONASS satellites on Indian launch vehicles. At the time of publication, April 2007, there are 12 operational GLONASS satellites and one newly launched GLONASS satellite at its commissioning phase. The Russian Government have set 2009 as the full deployment date of the 24-satellite constellation and ensured financial support to meet that date.[2]

The OEMV-2 and OEMV-3 receivers acquire and track GPS and GLONASS signals. Combined GPS and GLONASS measurements allow both real-time and post-processing GNSS applications. OEMV-based output is compatible with GrafNav post-processing software from NovAtel's Waypoint Products Group. Visit our website at http://www.novatel.com/products/waypoint_pps.htm for details.

1. This GLONASS Overview section was originated, and reviewed, with contributions from Professor Richard B. Langley, Geodetic Research Laboratory, Department of Geodesy and Geomatics Engineering, University of New Brunswick, Fredericton, N.B., Canada E3B 5A3; http://www.unb.ca/GGE/

2. Refer to the Russian Space Agency's website at http://www.glonass-ianc.rsa.ru

5.1 GLONASS System Design

As with GPS, the GLONASS system uses a satellite constellation to provide, ideally, a GLONASS receiver with six to twelve satellites at most times. A minimum of four satellites in view allows a GLONASS receiver to compute its position in three dimensions, as well as become synchronized to the system time.

The GLONASS system design consists of three parts:

- The Control segment
- The Space segment
- The User segment

All these parts operate together to provide accurate three-dimensional positioning, timing and velocity data to users worldwide.

5.1.1 The Control Segment

The Control Segment consists of the system control center and a network of command tracking stations across Russia. The GLONASS control segment, similar to GPS, must monitor the status of satellites, determine the ephemerides and satellite clock offsets with respect to GLONASS time and UTC (Coordinated Universal Time), and twice a day upload the navigation data to the satellites.

5.1.2 The Space Segment

The Space Segment is the portion of the GLONASS system that is located in space, that is, the GLONASS satellites that provide GLONASS ranging information. When complete, this segment will consist of 24 satellites in three orbital planes, with eight satellites per plane. *Figure 11, View of GPS and GLONASS Satellite Orbit Arrangement* on *Page 31* shows a combined GPS and GLONASS satellite system.

5.1.3 The User Segment

The User Segment consists of equipment (such as a NovAtel OEMV family receiver) that tracks and receives the satellite signals. This equipment must be capable of simultaneously processing the signals from a minimum of four satellites to obtain accurate position, velocity and timing measurements. Like GPS, GLONASS is a dual military/civilian-use system. The system's potential civil applications are many and mirror those of GPS.

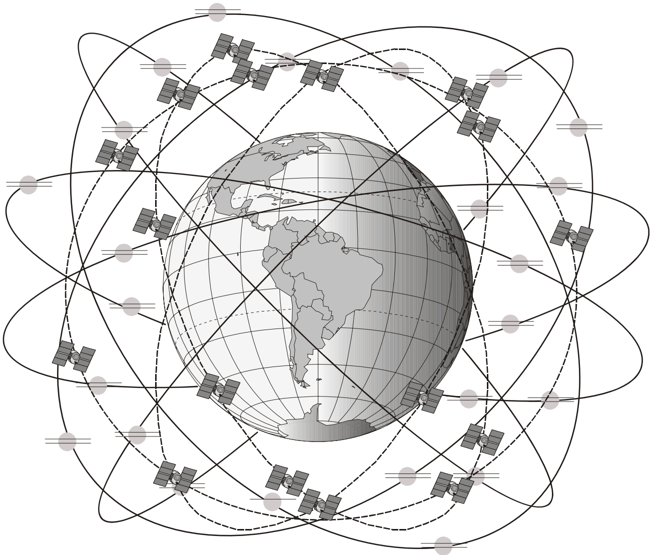

Figure 11: View of GPS and GLONASS Satellite Orbit Arrangement

Following are points about the GLONASS space segment:

- The geometry repeats about once every 8 days. The orbit period of each satellite is approximately 8/17 of a sidereal day such that, after eight sidereal days, the GLONASS satellites have completed exactly 17 orbital revolutions. A sidereal day is the rotation period of the Earth relative to the equinox and is equal to one calendar day (the mean solar day) minus approximately four minutes.
- Because each orbital plane contains eight equally spaced satellites, one of the satellites will be at the same spot in the sky at the same sidereal time each day.
- The satellites are placed into nominally circular orbits with target inclinations of 64.8 degrees and an orbital height of about 19,140 km, which is about 1,050 km lower than GPS satellites.
- The GLONASS satellite signal identifies the satellite and provides:
    - the positioning, velocity and acceleration vectors at a reference epoch for computing satellite locations
    - synchronization bits
    - data age
    - satellite health
    - offset of GLONASS time from UTC (SU) (formerly Soviet Union and now Russia)
    - almanacs of all other GLONASS satellites
- Some of the GLONASS transmissions initially caused interference to radio astronomers and mobile communication service providers. The Russians consequently agreed to reduce the number of frequencies used by the satellites and to gradually change the L1 frequencies in the future to 1598.0625 - 1605.375 MHz. Eventually the system will only use 12 primary frequency channels (plus two additional channels for testing purposes).

5.1.3.1 GPS and GLONASS Satellite Identification

The GLONASS satellites each transmit on slightly different L1 and L2 frequencies, with P- code on both L1 and L2, and with C/A code, at present, only on L1. GLONASS-M satellites reportedly[1] transmit the C/A code on L2.

Every GPS satellite transmits the L1 frequency centered at 1575.42 MHz. The GPS satellites are identifiable by their Pseudorandom Code Number (PRN) with a NovAtel receiver.

Unlike GPS, all GLONASS satellites transmit the same code at different frequencies. They derive signal timing and frequencies from one of three on-board cesium atomic clocks operating at 5 MHz:

For example,

L1 = 1602 MHz + (n x 0.5625) MHz

where

n = the frequency channel number (n = 0, 1, 2 and so on)

It means that satellites transmits signals on their own frequency, separated by multiples of 0.5625 MHz or 562.5 kHz, from the frequency of other satellites. See also *Figure 12* below.

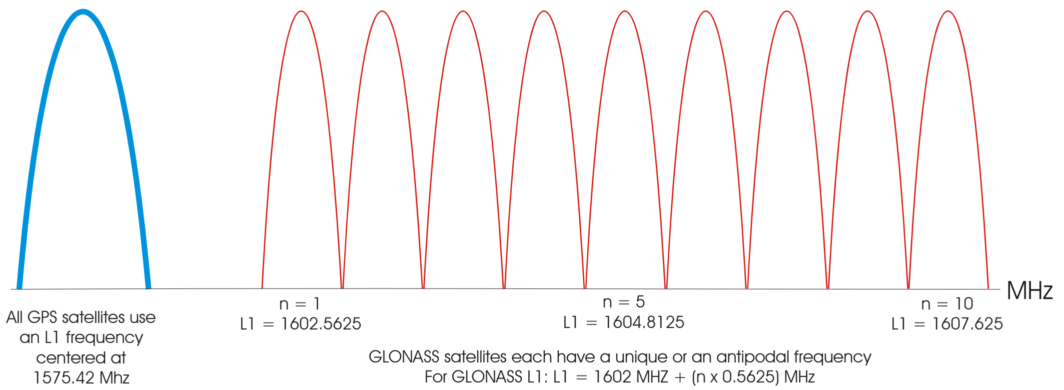

Figure 12: GPS and GLONASS L1 Frequencies

The signals are right-hand circularly polarized, like GPS signals, and have comparable signal strength.

GLONASS accomplishes system operation (24 satellites and only 12 channels) by having antipodal satellites transmit on the same frequency. Antipodal satellites are in the same orbit plane separated by 180 degrees in argument of latitude. This is possible because the paired satellites will never appear at the same time in view of an operational receiver that is on the Earth's surface, see *Figure 13, GLONASS Antipodal Satellites* on *Page 33*. At the time of publication, April 2007, four pairs of operational satellites share frequencies.

1. Refer to the GLONASS Interface Control Document (ICD), Version 5.0, Moscow, 2002 for more details. You can find GLONASS contact information on *Page 51*.

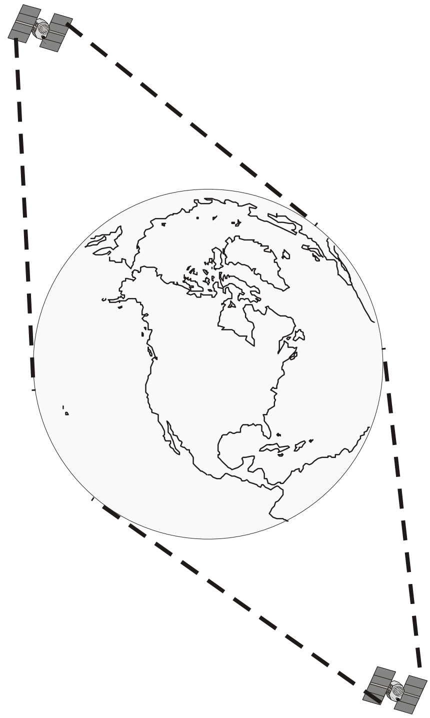

Figure 13: GLONASS Antipodal Satellites

A comparison of GPS with GLONASS satellites, signals and messages is in *Table 2* on *Page 35*.

5.2 Time

As stated earlier, both GPS and GLONASS satellites broadcast their time within their satellite messages. NovAtel's OEMV family of receivers are able to receive and record both time references as well as report the offset information between GPS and GLONASS time. Although similar, GPS and GLONASS have several differences in the way they record and report time. Please see the following sections for information on GPS and GLONASS time, as well as on how NovAtel's OEMV receivers are GPS week rollover compliant.

5.2.1 GPS Time vs. Local Receiver Time

All logs output by the receiver report GPS Time expressed in GPS weeks and seconds into the week. The time reported is not corrected for local receiver clock error. To derive the closest GPS Time, you must subtract the clock offset shown in the TIME log from GPS Time reported, refer to the *OEMV Family Firmware Reference Manual*[1].

1. NovAtel User Manuals are available from our website at:

   http://www.novatel.com/support/docupdates.htm.

GPS Time is based on an atomic time scale. Coordinated Universal Time as maintained by the U.S. Naval Observatory (UTC (USNO) reported in NMEA logs) is also based on an atomic time scale, with an offset of an integer number of seconds with respect to GPS Time. GPS Time is designated as being coincident with UTC (USNO) at the start date of January 6, 1980 (00 hours). GPS Time does not count leap seconds, and therefore an offset exists between UTC (USNO) and GPS Time (at this date in April 2007: 14 seconds). The GPS week consists of 604800 seconds, where 000000 seconds is at Saturday/Sunday midnight GPS Time. Each week at this time, the week number increments by one, and the seconds into the week resets to 0.

5.2.2 GLONASS Time vs. Local Receiver Time

GLONASS time is based on an atomic time scale similar to GPS. This time scale is UTC as maintained by Russia (UTC (SU)).

Unlike GPS, the GLONASS time scale is not continuous and must be adjusted for periodic leap seconds. Leap seconds are applied to all UTC time references as specified by the International Earth Rotation and Reference System Service (IERS). Leap seconds are used to keep UTC close to mean solar time. Mean solar time, based on the spin of the Earth on its axis, is not uniform and its rate is gradually changing due to tidal friction and other factors such as motions of the Earth's fluid core.

GLONASS time is maintained within 1 ms, and typically better than 1 microsecond (μs), of UTC (SU) by the control segment with the remaining portion of the offset broadcast in the navigation message. As well, Moscow offsets GLONASS time from UTC (SU) by plus three hours. The *GLOCLOCK* log, refer to the *OEMV Family Firmware Reference Manual*, contains the offset information between GPS and GLONASS time.

5.3 Datum

A datum is a set of parameters (translations, rotations, and scale) used to establish the position of a reference ellipsoid with respect to points on the Earth’s crust. If not set, the receiver’s factory default value is the World Geodetic System 1984 (WGS84).

GLONASS information is referenced to the Parametri Zemli 1990 (PZ-90, or in English translation, Parameters of the Earth 1990, PE-90) geodetic datum, and GLONASS coordinates are reconciled in the receiver through a position filter and output to WGS84.

See also the DATUM command in the *OEMV Family Firmware Reference Manual*, available in PDF format from our website at http://www.novatel.com/support/docupdates.htm.

Table 2: Comparison of GLONASS and GPS Characteristics

Parameter	Detail		GLONASS	GPS
Satellites	Number of satellites		21 + 3 spares [a]	21 + 3 spares [a]
	Number of orbital planes		3	6
	Orbital plane inclination (degrees)		64.8	55
	Orbital radius (kilometers)		25 510	26 560
Signals	Fundamental clock frequency (MHz)		5.0	10.23
	Signal separation technique [b]		FDMA	CDMA
	Carrier frequencies (MHz)	L1	1598.0625 - 1609.3125[c]	1575.42
		L2	1242.9375 - 1251.6875	1227.6
	Code clock rate (MHz)	C/A	0.511	1.023
		P	5.11	10.23
	Code length (chips)	C/A	511	1 023
		P	5.11×10^6	6.187104×10^{12}
C/A-code Navigation Message	Superframe duration (minutes)		2.5	12.5
	Superframe capacity (bits)		7 500	37 500
	Superframe reserve capacity (bits)		~620	~2 750
	Word duration (seconds)		2.0	0.6
	Word capacity (bits)		100	30
	Number of words within a frame		15	50
	Technique for specifying satellite ephemeris		Geocentric Cartesian coordinates and their derivatives	Keplarian orbital elements and perturbation factors
	Time reference [d]		UTC (SU)	UTC (USNO)
	Position reference (geodetic datum) [e]		PZ-90	WGS84

a. At the time of publication, April 2007, there are 29 operational GPS satellites and 12 operational GLONASS satellites in orbit.

b. Full GLONASS system operation will consist of 24 satellites and only 12 channels. Such a system of simultaneous multiple transmissions is known as frequency division multiple access (FDMA) and distinguishes GLONASS from GPS, which is a code division multiple access (CDMA) system. See also *Section 5.1.3.1, GPS and GLONASS Satellite Identification* starting on *Page 32*.

c. Refer to the GLONASS Interface Control Document (ICD), Version 5.0, Moscow, 2002 for more details. You can find GLONASS contact information on *Page 51*.

d. GLONASS and GPS use different time systems. GLONASS time is referenced to UTC (SU), the Russian National Etalon time scale, whereas, GPS Time is referenced to UTC as maintained by the U.S. Naval Observatory – UTC (USNO). The GLONASS control segment periodically applies a time step to bring the system's time within several hundred nanoseconds of UTC.

e. GLONASS ephemerides are referenced to the Parametry Zemli 1990 (PZ-90, or in English translation, Parameters of the Earth 1990, PE-90) reference frame. The realization of the PZ-90 frame through adopted reference station coordinates has resulted in offsets in origin and orientation as well as a difference in scale with respect to WGS84 used by GPS. Relationships between PZ-90 and WGS84 have now been established.

Chapter 6 Galileo

This chapter is intended to give you information on the Galileo[1] signals and their use.

6.1 Overview

Galileo will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. It will be inter-operable with GPS and GLONASS, the two other global satellite navigation systems.

A user will be able to take a position with the same receiver from any of the satellites in any combination. By offering dual frequencies as standard, however, Galileo will deliver real-time positioning accuracy down to the metre range, which is unprecedented for a publicly available system.

It will guarantee availability of the service under all but the most extreme circumstances and will inform users within seconds of a failure of any satellite. This will make it suitable for applications where safety is crucial, such as running trains, guiding cars and landing aircraft.

The first experimental satellite, part of the so-called Galileo System Test Bed (GSTB) was launched in the second semester of 2005. The objective of this experimental satellite is to characterize the critical technologies, which are already in development under European Space Agency (ESA) contracts. Thereafter up to four operational satellites will be launched in the 2007-2008 time frame to validate the basic Galileo space and related ground segment. Once this In-Orbit Validation (IOV) phase has been completed, the remaining satellites will be installed to reach the Full Operational Capability (FOC) in 2010.

The fully deployed Galileo system consists of 30 satellites (27 operational + 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes in 23616 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees with reference to the equatorial plane. Once this is achieved, the Galileo navigation signals will provide a good coverage even at latitudes up to 75 degrees north, which corresponds to the North Cape, and beyond. The large number of satellites together with the optimisation of the constellation, and the availability of the three active spare satellites, will ensure that the loss of one satellite has no discernible effect on the user.

Two Galileo Control Centres (GCC) will be implemented on European ground to provide for the control of the satellites and to perform the navigation mission management. The data provided by a global network of twenty Galileo Sensor Stations (GSS) will be sent to the Galileo Control Centres through a redundant communications network. The GCC's will use the data of the Sensor Stations to compute the integrity information and to synchronize the time signal of all satellites and of the ground station clocks. The exchange of the data between the Control Centres and the satellites will be performed through so-called up-link stations. Five S-band up-link stations and 10 C-band up-link stations will be installed around the globe for this purpose.

As a further feature, Galileo will provide a global Search and Rescue (SAR) function, based on the operational search and rescue satellite aided tracking Cospas-Sarsat system. To do so, each satellite

1. Galileo Overview information from ESA Navigation website - http://www.esa.int/esaCP/index.html

will be equipped with a transponder, which is able to transfer the distress signals from the user transmitters to the Rescue Co-ordination Centre (RCC), which will then initiate the rescue operation. At the same time, the system will provide a signal to the user, informing them that their situation has been detected and that help is under way. This latter feature is new and is considered a major upgrade compared to the existing system, which does not provide a feedback to the user.

Five categories of services have been defined:

1. A free Open Service (OS)
2. A highly reliable Commercial Service (CS)
3. A Safety-of-Life Service (SOL)
4. A government encrypted Public Regulated Service (PRS)
5. A Search and Rescue Service (SAR)

6.1.1 Open Service

This single-frequency service will involve the provision of a positioning, navigation and precise timing service. It will be available for use by any person in possession of a Galileo receiver. No authorisation will be required to access this service. Galileo is expected to be similar to GPS in this respect.

The principal applications will be general navigation and positioning, network timing, traffic information systems, systems including information on alternative routes in the event of congestion, and wireless location, for example, with mobile telephony.

Studies clearly show that the availability of these services will be significantly enhanced by the existence of a greater number of satellites, as is the case when both GPS and Galileo are in operation. This is particularly important for land-based services, such as private car navigation, where service is mostly required in down town cores and where satellite shadowing is minimised by the combination of the systems.

The Open Service will be transmitted in the E5a frequency band at 1176.45 MHz.

6.1.2 Commercial Service

Service providers using the multi-frequency commercial services will have the opportunity to give added value to their range of products for which they can charge the end customer and will, in turn, pay a fee to the Galileo operator. The signal will contain data relating to the additional commercial services being offered. In return for the fee, the Galileo operator will be able to offer certain service guarantees. This aspect of service guarantee and the commensurate liabilities is one area where Galileo is significantly differentiated from GPS. A key component in achieving this is an independent system within Galileo for monitoring the satisfactory working of the system and informing the end user of this by an integrity signal incorporated in the data stream.

The main applications for this service concern professional users who are ready to pay for a service guaranteed by the Galileo operator, notably in the areas of technical surveys, in activities involving customs and excise operations, network synchronisation, sea fleet management, vehicle fleet management, and road tolls.

Controlled access to this service for end-users and the providers of value-added services will be based on protected access keys in the receivers. This will also enable revenue to be collected from users.

The commercial service will be transmitted in the E6 frequency band at 1278.75 MHz.

6.1.3 Safety-of-Life Service

The safety-of-life service will be offered to users who are highly dependant on precision, signal quality and signal transmission reliability. It will offer a high level of integrity, and consequently, provide the user with a very rapid warning of any possible malfunctions. It will need to be certified in accordance with the regulations applicable to the various modes of transport (the International Civil Aviation Organization (ICAO) regulations in the case of air transport; the International Maritime Organization (IMO) regulations in the case of sea transport). This service will require specialised receivers providing access to this enhanced-quality signal.

The safety-of-life service will be transmitted in two frequency bands – L1 at 1575.42 MHz, and E5b at 1207.14 MHz. Users may receive signals from the two frequency bands independently.

6.1.4 Public Regulated Service

The PRS will be a restricted access service, offered to government agencies that require a high availability navigation signal. The PRS service will utilize ranging codes that are encrypted with a highly secure government encryption scheme. To enhance availability, the PRS service is intended to have anti-jamming and anti-spoofing capabilities.

The PRS will be transmitted in two frequency bands – L1 at 1575.42 MHz, and E6 at 1278.75 MHz. Users may receive signals from the two frequency bands independently.

6.1.5 Search and Rescue Service

A specific public service designed to assist in search and rescue operations will make it possible to locate person and vehicles in distress. The vehicles will be fitted with beacons, which having been activated in the event of an emergency will send an alerting signal to the rescue centre.

The Galileo Programme provides this search and rescue service for users based on humanitarian and public service principles of the international COSPAS-SARSAT system while at the same time making search and rescue operations more effective.

6.2 L1L5E5a Receiver

NovAtel’s L1L5E5a receiver offers superior 16 channel tracking of GPS L1/L5, Galileo L1/E5a and SBAS signals, in a Euro form-factor card, packaged in the popular EuroPak enclosure:

- Tracks and decodes GPS L1 and L5, SBAS L1 and L5, and Galileo L1 and E5a
- Digital Pulse Blanking on GPS L1 and L5 and Galileo L1 and E5a for radar and pulsed DME interference mitigation
- Includes L1 GPS RFI improvements as developed for the US WAAS reference receivers
- External OXCO input and enclosure option with internal OCXO

See also *Section 7.2, NovAtel’s GNSS Modernization* on *Page 39*.

Chapter 7 L2C Overview

Currently, Block II/IIA and Block IIR NAVSTAR GPS satellites transmit the civilian C/A code on the L1 frequency, and the military P(Y) code on both the L1 and L2 frequencies. The new Block IIR-M satellites will transmit the same signals as the previous two blocks, but will also have a new signal, called L2C, on the L2 frequency.

L2 has a carrier frequency of 1227.60 MHz. L2C has two codes, the moderate length code (CM) and the long code (CL). The CM code carries data while the CL is the pilot signal. The CM code is 10,230 chips long and repeats every 20 milliseconds. It is bi-phase modulated with message data. The CL code is 767,250 chips long and repeats every 1.5 seconds.

Since L2 is shared between civil and military signals, L2C is limited to a single bi-phase component in quadrature with the P(Y) code. Even with L2C limited to a 1.023 MHz clock rate to maintain spectral separation from the military M code, there is an important advantage in having two codes. The advantage stems from the fact that L2C time-multiplexes two codes of different length. The CM is bi-phase modulated with data and the CL has no data modulation. The composite signal is clocked at 1.023 MHz, and alternates between chips of each code.

The L2C and L1 C/A codes ensure that there are always two accessible civilian codes.

7.1 Application Examples

Here are a few of the many dual-frequency civil users, many of who needed a civil code to replace semi-codeless tracking:

- Scientific: earthquakes, volcanoes, continental drift, weather
- Cadastral and construction land survey
- Guidance and control: mining, construction, agriculture
- Land and offshore land and mineral exploration
- Marine survey and construction

7.2 NovAtel’s GNSS Modernization

NovAtel’s OEMV-3 GNSS engine is a triple frequency board that includes L2C, GLONASS measurements and hardware support for the future L5 GPS frequency. It is a drop-in replacement for the OEM4-G2 with compatible commands and logs.

The EuroPak-L1L5E5a receiver offers superior 16 channel tracking of GPS L1/L5, Galileo L1/E5a and SBAS signals. See also *Section 6.2, L1L5E5a Receiver* on *Page 38*

While providing today’s leading edge technology, the WAAS G-II has the added advantage of expandability for the future. With the capability to hold up to 12 Euro form factor cards in three independent receiver sections, the WAAS G-II is ready to support additional receiver cards for tracking such signals as GPS L5 and L2C, Galileo, and GLONASS. As a result, the WAAS G-II is ready for the future in the world’s wide area reference networks.

Chapter 8 L5 Overview

The United States plans to implement a third civil GPS frequency (L5[1]) at 1176.45 MHz beginning with the first Block IIF NAVSTAR GPS satellite to be launched in 2007. This frequency is located within the 960-1215 MHz frequency band already used worldwide for Aeronautical Radio Navigation Services (ARNS) as well as by the Department of Defense (DoD). Certain measures have been taken within the United States to ensure that L5 can coexist with government systems operating at the same or nearby frequencies.

The carriers of the L5 signal are modulated by two bit streams in phase quadrature. The L5 power spectrum is contained within a 24 MHz band centered about L5. L5 power is increased by 6 dB compared to the L1 signal (-154 dBW versus -160 dBW). This is equally split between an in-phase (I) data channel and a quadrature (Q) data-free channel, which improves resistance to interference, especially from pulse emitting systems in the same band as L5. Both I and Q channels are encoded with the Neuman-Hoffman codes. The L5 signal is also Forward Error Correction (FEC) encoded. Code Division Multiple Access (CDMA) techniques allow differentiation between the SVs since all SVs transmit the same L5 frequency.

The benefits of the L5 signal include:

- Signal redundancy, where the L5 signal is completely redundant to the L1 signal, creates frequency diversity and includes a direct acquisition capability so that you do not have to rely on the L1 and L2 signals for initial acquisition
- Civilian capability to perform ionospheric delay corrections
- Higher integrity level and continuity of service
- Enhanced interference rejection capabilities
- Coherent data-free component allows the receiver to track the carrier at lower signal-to-noise ratios
- Neuman-Hoffman encoding reduces the effect of narrowband interference and improves the cross-correlation properties between SV signals
- FEC encoding permits a receiver to correct errors introduced in the transmission process due to noise or interference and makes it easier to extract the navigation message from weak signals
- 6 dB stronger signal and more robust signal structure than L1
- Greater reliability for safety-of-life applications, interference mitigation worldwide, and position accuracies are provided

The OEMV-3 is hardware-capable for tracking L5 but requires a future firmware upgrade to enable L5 positioning. This will be available when a usable number of satellites are in orbit. See also *Section 7.2, NovAtel's GNSS Modernization* on *Page 39*.

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1. For further information on the L5 signal, you may wish to refer to: *NAVSAT GPS L5 Signal Specification*, Document No. RTCA/DO-261. See also RTCA contact details on *Page 50*.

Chapter 9 Multipath

Multipath signal reception is one of the most plaguing problems that detracts from the accuracy potential of GNSS differential positioning systems. This section provides a brief look at the problems of multipath reception and some solutions.

Multipath antenna hardware solutions, such as site selections away from structures that block the satellite signal or reflective surfaces that distort the signal, are capable of achieving varying degrees of multipath reception reduction. For example, site selection A, as seen in *Figure 14*, will mean less multipath reception than site selection B.

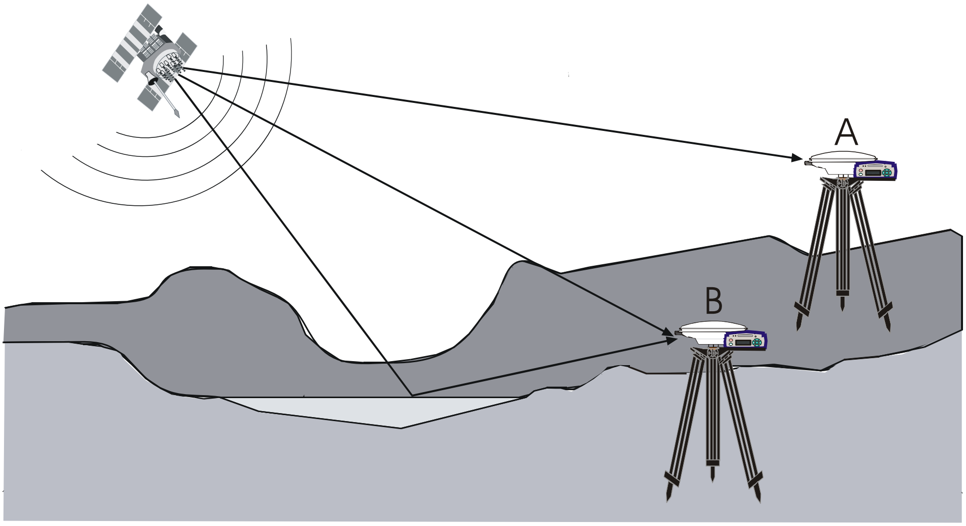

Figure 14: GNSS Signal Multipath vs. Increased Antenna Height

You must also have the correct antenna type for the types of frequencies (for example L1, L2 or L-band) you are tracking. These options, however, require specific conscious efforts on the part of the GNSS user. In many situations, especially kinematic, few (if any) of the above solutions will be effective, or even possible, to incorporate. By far, the best solutions are those that require little or no special efforts in the field on the part of the GNSS user. This is what makes NovAtel's internal receiver solutions so desirable and practical.

NovAtel has placed long term concerted effort into the development of internal receiver solutions and techniques that achieve multipath reduction, all of which are transparent to the receiver user. These achievements have led first to Narrow Correlator tracking technology and then PAC technology that utilizes innovative patented correlator delay lock loop (DLL) techniques.

With patented PAC technology, and a powerful 32-bit processor, the OEMV family receivers offer multipath-resistant processing at high data update rates. Excellent acquisition and re-acquisition times allow the receivers to operate in environments where very high dynamics and frequent interruption of signals can be expected.

9.1 Multipath Basics

Multipath errors are GNSS errors caused by the interaction of the GNSS satellite signal and its reflections as in *Figure 15*. Multipath is inescapable even with careful setups away from obvious reflectors because of the constantly moving GNSS satellite constellations.

Antenna hardware solutions are capable of achieving varying degrees of multipath suppression. NovAtel's internal receiver solutions are a desirable and practical accompaniment.

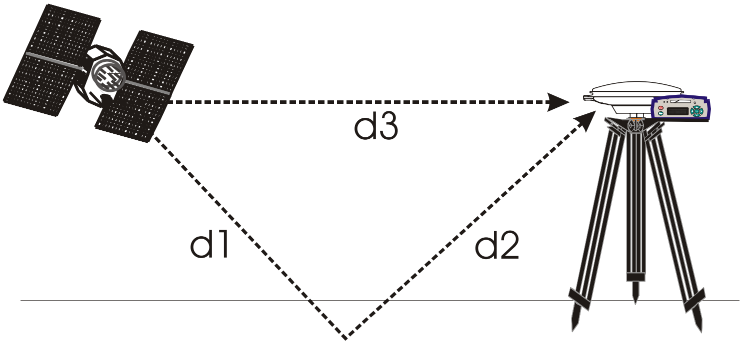

Figure 15: Multipath

9.1.1 Pseudorange and Code Chips

Notice in *Figure 15*, how the signal path (d1 + d2) is longer than the d3 path. This multipath delay, the additional time for the signal to travel (d1 + d2), can also be seen in *Figure 19, Comparison of Multipath Envelopes* on *Page 45*.

Searching for a GNSS signal uses the mathematical process of correlation. Correlation is used to find the relationship between the errors in position and time between the measurements.

The GPS satellite signal identifies the satellite and provides the positioning, timing, ranging data, satellite status and the corrected ephemerides (orbit parameters) of the satellite to the users. The satellites can be identified either by the Space Vehicle Number (SVN) or the Pseudorandom Code Number (PRN). The PRN is used by NovAtel receivers.

The coarse acquisition (C/A) code is a pseudorandom string that allows the range to the receiver to be calculated using the satellite's unique identity. C/A code is modulated by a chipping sequence.

To convert code chips to meters for the L1 frequency, divide the speed of light by the signal's chipping rate, which for L1 is 1.023 MHz so that:

$$1 \text{ chip} = 293.05 \text{ m}$$

The pseudorange is measured to four satellites and solved for four unknowns (x, y, z and τ where τ is the clock bias). However, other error sources exist which are not so easily removed.

For example, satellite orbit and satellite clock errors come from the satellite. Atmospheric errors, such as ionospheric and tropospheric errors, can be larger than those due to multipath. Software models are used to compensate for these. There may be errors from radio frequency (RF) noise such as jamming. Closer to the antenna, there are also receiver noise errors, filtering errors and multipath errors. We concentrate on the latter in here.

The pseudorange is calculated by measuring the time delay, Δt (see also *Figure 16*), between the received signal code from the satellite and the replica code generated by the receiver. The pseudorange measurement is given by: $psuedorange = \Delta t \times C$ where C is the speed of light.

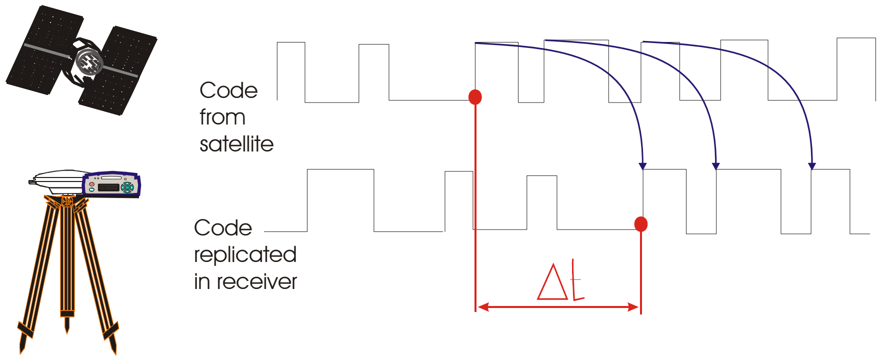

Figure 16: Time Delay

PAC improves accurate reception of C/A code and also reduces the effect of multipath on pseudorange measurements. The code accuracy is important to carrier phase positioning, used in high-accuracy applications such as real-time kinematic (RTK) survey, because the receiver can accurately start carrier phase measurements based on C/A code. Poor code measurements, where a potential cause is multipath, can lead to poor RTK fixes.

9.1.2 Tracking Loops and Correlators

PAC utilizes innovative, patented correlator delay lock loop (DLL) techniques.

As stated previously, correlators find the relationship in the code between the errors in position and time between measurements. All GNSS receivers use correlators to track signals but consumer-grade receivers typically use ‘wide-correlators’. In practice, the GNSS signal is distorted to some extent by multipath and other phenomena. Wide correlators track the distorted signal with some error. Narrow correlators more easily reject this distortion.

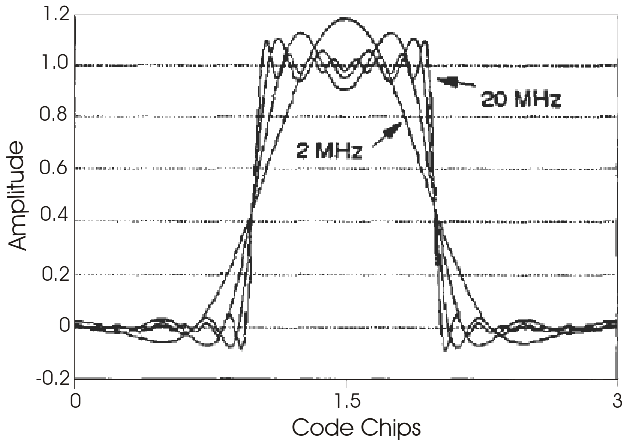

Figure 17: C/A Code Distortion

The NovAtel receiver uses the entire signal bandwidth broadcast by the GNSS satellites. Consumer-grade receivers typically band limit this signal to 2 MHz. *Figure 17* [1] on *Page 43* shows that the narrower the filter becomes, the more sinusoidal the transitions of the C/A code become. By utilizing PAC tracking techniques, the receiver is capable of pseudorange measurement improvements better than 4:1 when compared to consumer-grade (wide) correlation techniques and 2:1 when compared to narrow correlation techniques. PAC dramatically reduces multipath reception. This is due to PAC's narrowed, and therefore more multipath resistant, pattern than other correlators. See also *Figure 18, Comparison of Correlator Patterns* below.

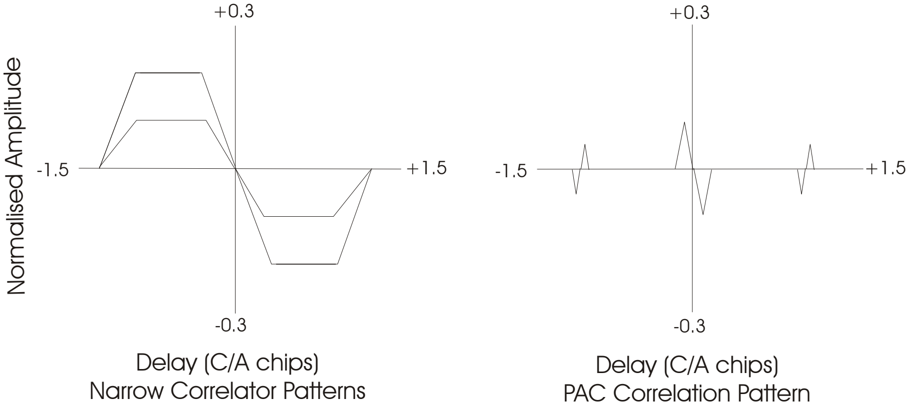

Figure 18: Comparison of Correlator Patterns

(representations from paper, not to scale)[2]

9.1.2.1 Pulse Aperture Correlator Technology (PAC)

NovAtel's OEM4 and OEMV family of receivers achieve a higher level of pseudorange positioning performance versus standard (wide) or narrow correlator receivers, by virtue of their celebrated PAC technology. By utilizing PAC tracking techniques, the receiver is capable of pseudorange measurement improvements better than 4:1 when compared to standard (wide) correlation techniques and 2:1 when compared to narrow correlation techniques. The PAC technology dramatically reduces multipath reception by virtue of its very narrow correlation function.

Figure 19, Comparison of Multipath Envelopes on *Page 45* illustrates relative multipath-induced tracking errors encountered by the different correlation technologies. As can be seen, standard correlators are susceptible to substantial multipath biases for C/A code chip delays of up to 1.5 code chips, with the most significant C/A code multipath bias errors occurring at about 0.25 to 0.75 code chips (approaching 80 m error). The Narrow Correlator tracking technology multipath susceptibility peaks at about 0.2 code chips (about 10 m error) and remains relatively constant out to 0.95 code chips where it rapidly declines to negligible error after 1.1 code chips. On the other hand the PAC

1. "NovAtel's GPS Receiver The High Performance OEM Sensor Of The Future"; Pat Fenton, Bill Falkenberg, Tom Ford and Keith Ng, NovAtel Inc.; AJ Van Dierendonck, AJ Systems http://www.novatel.com/Documents/Papers/File1.pdf

2. "Theory and Performance of the Pulse Aperture Correlator"; J. Jones, P. Fenton and B. Smith, NovAtel Inc. http://www.novatel.com/Documents/Papers/PAC.pdf

technology multipath susceptibility peaks at about 0.1 code chips (about 5 m error) then reduces to a negligible amount at about the 0.2 code chip mark.

While positioning in single point mode, the multipath and ranging improvement benefits of a PAC technology receiver versus narrow or standard correlators, are overridden by a multitude of GNSS system biases, atmospheric and other errors. With or without PAC in single point mode, positioning accuracy will be in the order of 1.8 m (CEP) using a consumer-grade wide correlator. However the benefits of PAC technology become most significant during pseudorange DGPS operation, where the GNSS system biases are largely removed.

Receivers operating DGPS (low multipath environment and using a choke ring ground plane or GPS-700 family antenna) with NovAtel's Narrow Correlator tracking technology receivers are able to achieve accuracies in the order of 0.75 m CEP. NovAtel's PAC technology receivers are able to achieve accuracies in the range of 0.35 to 0.5 m CEP. PAC technology achieves this higher accuracy through a combination of low noise ranging measurements and a very narrow correlation window that dramatically reduces the effects of multipath interference and distortion.

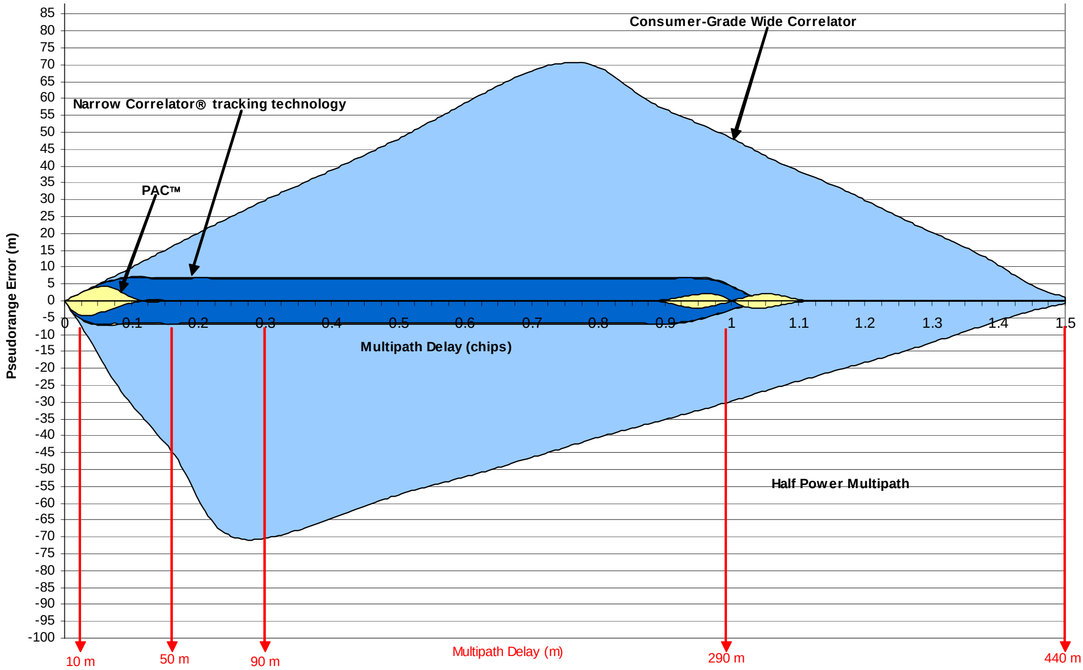

Figure 19: Comparison of Multipath Envelopes

9.2 Summary

Any localized propagation delays or multipath signal reception cause biases to the GNSS ranging measurements that cannot be differenced by traditional DGPS single or double-differencing techniques. Multipath is recognized as one of the greatest sources of errors encountered by a system operating in single-point or differential mode. It has been discussed that careful site selection and a GPS-700-series antenna, or good antenna design combined with a choke ring ground plane, are fairly effective means of reducing multipath reception. Internal receiver solutions for multipath elimination are achieved through various types of correlation techniques, where the "standard correlator" is the reference by which all other techniques can be compared.

PAC technology has a four fold advantage over standard correlators. Reasons for this advantage are improved ranging measurements due to a sharper, less noisy correlation peak, and reduced susceptibility to multipath due to rejection of C/A code delays of greater than 0.1code chip. When used with a choke ring ground plane, PAC technology provides substantial performance gains over standard or narrow correlator receivers operating in differential mode.

Chapter 10 TTFF and Satellite Acquisition

Time to First Fix (TTFF), is the time it takes the receiver to calculate a position after a reset or upon power-up. The TTFF varies and depends on what is stored in non-volatile memory (NVM) at the time of power-up, and on what other information is available, such as almanac, ephemeris or time.

The speed at which the receiver locates and locks onto new satellites is improved if the receiver has approximate time and position, as well as an almanac. This allows the receiver to compute the elevation of each satellite so it can tell which satellites are visible and their Doppler offsets, improving TTFF.

Without this information, the receiver must blindly search through all possible satellite PRN codes and Doppler offsets (as in a cold start).

Re-acquisition is the resumption of tracking and measurement processing after a brief loss of lock.

10.1 OEMV-based Products

Once satellites are acquired, the receiver will normally require another 18-36 seconds to receive broadcast ephemeris data to calculate a position. To avoid this delay, the receiver saves ephemeris data in its NVM and will use that data if it is less than 2 hours old.

Table 3: Typical Receiver TTFF for OEMV-Based Products

Mode	Information Available to the Receiver				Typical TTFF
	Approx. Position	Approx. Time	Almanac	Recent Ephemeris	
Cold Start (No almanac or ephemeris and no approximate position or time)	no	no	no	no	50 s
Warm Start (Almanac, approximate position and time, no recent ephemeris)	yes	yes	yes	no	40 s
Hot Start (Almanac and recent ephemeris saved and approximate position)	yes	yes	yes	yes	30 s

✉ The TTFF numbers quoted assume an open environment. Poor satellite visibility or frequent signal blockage increases TTFF.

Upon power-up, the receiver does not know its position or time, and therefore, cannot use almanac information to aid satellite acquisition. To aid in initial positioning or timing, you can set an approximate GPS Time using the SETAPPROXTIME command or RTCAEPHEM message. The

RTCAEPHEM message contains GPS week and seconds and the receiver will use that GPS Time if the time is not yet known. Several logs provide base station coordinates and the receiver will use them as an approximate position allowing it to compute satellite visibility. Alternately, you can set an approximate position by using the SETAPPROXPOS command, or any of the following messages: RTCAREF, CMRREF or the RTCMV3 messages.

The OEMV does not use a real-time clock. Approximate time and position must be used in conjunction with a current almanac to aid satellite acquisition. For a summary of the OEMV family command and logs used to inject an approximated time or position into the receiver, see *Table 4* (or the *OEMV Family Firmware Reference Manual*).

Table 4: Approximate Time and Position Methods

Approximate	Command	Log
Time	SETAPPROXTIME	RTCAEPHEM
Position	SETAPPROXPOS	RTCAREF *or* CMRREF *or* RTCM3

Base station aiding can help in environments such as urban canyons or forests where there can be frequent loss of lock or, when no recent ephemerides (new or stored) are available. A set of ephemerides can be injected into a rover station by broadcasting the RTCAEPHEM message from a base station. GPS ephemeris is three frames long within a sequence of five frames. Each frame requires 6 seconds of continuous lock to collect the ephemeris data. This gives a minimum of 18 s and a maximum of 36 s continuous lock time.

10.2 SUPERSTAR II-based Products

The receiver enters Navigation mode (refer to the *Operational States* section of the *SUPERSTAR II User Manual*) and provides valid outputs in less than 45 s (warm start) after completion of the self-test and the following initialization criteria have been met:

1. Valid time (±10 minutes) and position data (±100 km) from actual position
2. Valid almanac data (less than a year old)
3. At least 4 satellites greater than 5° elevation above the horizon
4. HDOP < 6

The maximum time for self-test and device initialization is less than 5 seconds.

In the case where the following additional conditions are met, the TTFF is reduced to 15 s (hot start):

- Unit has not been off for more than a week before nominal power is re-applied
- Last navigation fix occurred within the last 2 hours
- Valid ephemeris data (less than 4 hours old) for at least 5 satellites

With no initialization, the time from power application to valid navigation output is typically 166 s

(cold start).

There is no disruption of navigation data output when a satellite signal is lost unless there is a power interruption for a period of less than or equal to 200 ms. Also, the receiver re-acquires the satellite signal within 0.3 seconds after satellite visibility has been restored.

When a satellite signal is lost due to signal masking, the signal is typically re-acquired within 2-3 seconds after the satellite signal meets the minimum input levels. The vehicle dynamics during the masking period are assumed to be less than or equal to 0.5 g acceleration and 100 m/s velocity.

When total signal masking occurs, navigation resumes within 3-5 seconds of a Navigation mode criteria being met.

The receiver is capable of acquiring satellite signals with a minimum input carrier-to-noise density ratio (C/N_0) to the correlator of 34 dB-Hz. Once a signal has been acquired, the receiver is capable of tracking satellite signals with a minimum input carrier-to-noise density ratio (C/N_0) to the correlator of 31 dB-Hz.

Chapter 11 Standards/References

✉ Website addresses are subject to change however they are accurate at the time of posting.

NOVATEL INC.

Contact your local NovAtel dealer first for more information. To locate a dealer in your area or if the problem is not resolved, contact NovAtel Inc. directly.

Customer Service Department
1120 - 68 Avenue NE
Calgary, AB., Canada, T2E 8S5

Phone: 1-800-NOVATEL (U.S. & Canada), or +1-403-295-4900Fax: +1-403-295-4901

E-mail: support@novatel.com Website: http://www.novatel.com

RTCM STANDARDS REFERENCE

For detailed specifications of RTCM, refer to RTCM SC104 Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.3

Radio Technical Commission For Maritime Services
1800 North Kent St., Suite 1600
Arlington, VA 22209, USA

Phone: +1-703-527-2000 Fax: +1-703-351-9932

E-Mail: information@rtcm.org Website: http://www.rtcm.org/

RTCA STANDARDS REFERENCE

For copies of the Minimum Aviation System Performance Standards DGNSS Instrument Approach System: Special Category-1 (SCAT-1), contact:

RTCA, Inc.
1828 L Street, NW
Suite 805
Washington, DC 20036

Phone: 202-833-9339 Fax: 202-833-9434

E-Mail: info@rtca.org Website: http://www.rtca.org

GPS SPS SIGNAL SPECIFICATION REFERENCE

For copies of the Interface Control Document (ICD)-GPS-200, contact:

ARINC Research Corporation
2551 Riva Road
Annapolis, MD 21401-7465

Phone: 800-633-6882 Fax: 410-573-3300

Website: http://www.arinc.com

NMEA REFERENCE

National Marine Electronics Association, 0183 Standard for Interfacing Marine Electronic Devices

NMEA Executive Director
Seven Riggs Avenue
Severna Park, MD 21146

Phone: 410-975-9425 Fax: 410-975-9450

E-Mail: info@nmea.org Website: http://www.nmea.org

GEODETIC SURVEY OF CANADA

Natural Resources Canada
Geodetic Survey Division
Geomatics Canada
615 Booth Street, Room 440
Ottawa, Ontario, Canada, K1A 0E9

Phone: (613) 995-4410 Fax: (613)995-3215

E-Mail: information@geod.nrcan.gc.ca Website: http://www.geod.nrcan.gc.ca/

U.S. NATIONAL GEODETIC SURVEY

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East - West Highway
Silver Spring, MD 20910-3282

Phone: (301)713-3242 Fax: (301)713-4172

E-Mail: ngs.infocenter@noaa.gov Website: http://www.ngs.noaa.gov

NAVSTAR GPS

NAVSTAR GPS
United States Naval Observatory (USNO)
3450 Massachusetts Avenue, NW
Washington, DC 20392-5420

Phone: (202) 762-1467

Website: http://tycho.usno.navy.mil/gps.html

GLONASS

Coordinational Scientific Information Center
Moscow, Russia

Phone: +7(495)333-72-00 Fax: +7(495)333-81-33

E-Mail: glonass-ianc@mcc.rsa.ru Website: http://www.glonass-ianc.rsa.ru

CDGPS

Province of British Columbia
Ministry of Sustainable Resource Management
Base Mapping and Geomatic Services
PO Box 9355, STN PROV GOVT
Victoria, BC, Canada, V8W 9M2

Phone: +1(250)387-6316 Fax: +1(250)356-7831

Website: http://www.cdgps.com/

OMNISTAR

OmniSTAR, Inc.
8200 Westglen Drive
Houston, TX 77063 USA

Phone: 1-800-338-9178 (U.S. & Canada), or +1-713-785-5850

E-Mail: dgps2@omnistar.com Website: http://www.omnistar.com/

SOCIETY OF AUTOMOTIVE ENGINEERING

SAE World Headquarters
400 Commonwealth Drive
Warrendale, PA 15096-0001 USA

Phone: (724)776-4841 Fax: (724)776-0790

E-Mail: CustomerService@sae.org Website: http://www.sae.org/servlets/index

Chapter 12 Unit Conversion

Sections 12.1 to *12.4* list commonly used equivalents between the SI (Système Internationale) units of weights and measures used in the metric system, and those used in the imperial system. A complete list of hexadecimal values with their binary equivalents is given in *Section 12.5* while an example of the conversion from GPS Time of week to calendar day is shown in *Section 12.6*.

12.1 Distance

1 meter (m) = 100 centimeters (cm) = 1000 millimeters (mm)

1 kilometer (km) = 1000 meters (m)

1 nautical mile = 1852 m

1 international foot = 0.3048 m

1 statute mile = 1609.344 m

1 US survey foot = 0.3048006096 m

1 inch = 25.4 mm

12.2 Volume

1 liter (l) = 1000 cubic centimeters (cc)

1 gallon (Imperial) = 4.546 liters

1 gallon (US) = 3.785 liters

12.3 Temperature

degrees Celsius = (5/9) x [(degrees Fahrenheit) - 32]

degrees Fahrenheit = [(9/5) x (degrees Celsius)] + 32

12.4 Weight

1 kilogram (kg) = 1000 grams

1 pound = 0.4536 kilogram (kg)

12.5 Hexadecimal, Binary and Decimal Equivalents

Hex	Binary	Decimal	Hex	Binary	Decimal	Hex	Binary	Decimal	Hex	Binary	Decimal
0	0000	0	4	0100	4	8	1000	8	C	1100	12
1	0001	1	5	0101	5	9	1001	9	D	1101	13
2	0010	2	6	0110	6	A	1010	10	E	1110	14
3	0011	3	7	0111	7	B	1011	11	F	1111	15

Binary	Decimal	Binary	Decimal	Binary	Decimal	Binary	Decimal
10000	16	100101	37	111010	58	1001111	79
10001	17	100110	38	111011	59	1010000	80
10010	18	100111	39	111100	60	1010001	81
10011	19	101000	40	111101	61	1010010	82
10100	20	101001	41	111110	62	1010011	83
10101	21	101010	42	111111	63	1010100	84
10110	22	101011	43	1000000	64	1010101	85
10111	23	101100	44	1000001	65	1010110	86
11000	24	101101	45	1000010	66	1010111	87
11001	25	101110	46	1000011	67	1011000	88
11010	26	101111	47	1000100	68	1011001	89
11011	27	110000	48	1000101	69	1011010	90
11100	28	110001	49	1000110	70	1011011	91
11101	29	110010	50	1000111	71	1011100	92
11110	30	110011	51	1001000	72	1011101	93
11111	31	110100	52	1001001	73	1011110	94
100000	32	110101	53	1001010	74	1011111	95
100001	33	110110	54	1001011	75	1100000	96
100010	34	110111	55	1001100	76	1100001	97
100011	35	111000	56	1001101	77	1100010	98
100100	36	111001	57	1001110	78	1100011	99
						1100100	100[a]

a.These binary to decimal equivalents only go up to decimal 100 for the purpose of example. Please use a calculator for other conversions.

12.6 GPS Time Conversions

The following sections provided examples for converting to and from GPS Time.

12.6.1 GPS Time of Week To Day of Week with Time of Day

The value given for GPS Time of Week represents the number of seconds into the week. Therefore, to determine the day and time from that value, calculations are performed to break down the number of seconds into day, hour, minute, and second values.

For example, starting with a GPS Time of Week of *511200 seconds*, the calculations are done as follows:

511200 seconds	Day of Week	511200 / 86400 seconds per day	**5**.916666667 **days**
	Hour	0.916666667 × 86400 / 3600 seconds per hour	**22**.0000 **hours**
	Minute	0.000 × 3600 / 60 seconds per minute	**0**.000 **minutes**
	Second	0.000 × 60 seconds per minute	**0**.000 **seconds**

Therefore, 511200 seconds represents *day 5 (Thursday) + 22 hours, 0 minutes, 0 seconds into Friday.*

12.6.2 Calendar Date to GPS Time

Converting a calendar date to GPS Time is calculated as shown in the example below, using the calendar date *13:30 hours, January 28, 2005*.

Years from January 6, 1980 to January, 28, 2005		25 years
Number of days in 25 years (25 years × 365 days/year)		9,125 days
Add one day for each leap year (a year which is divisible by 4 but not by 100, unless it is divisible by 400 as every 100 years a leap year is skipped)	+	7 days
Add days from January 6 to January 27 (January 28th is not finished)	+	22 days
Total days	=	9,154 days
Total number of seconds (9154 days × 86400 seconds/day)	=	790,905,600 seconds
Total number of weeks (790,905,600 seconds / 604,800 seconds/week)	=	**1307**.714285 **weeks**
Days into week (0.714285 × 7 days/week)		5 days
Number of seconds in 5 days (5 days × 86400 seconds/day)		432,000 seconds
Add number of seconds into the 6th day, January 28th (13.5 hours × 3600 seconds/hour)	+	48,600 seconds
Total seconds into week	=	**480,600 seconds**

The resulting value for GPS Time is *Week 1307, 480,600 seconds*.

Chapter 13 Electrostatic Discharge Control (ESD) Practices

13.1 Overview

Static electricity is electrical charge stored in an electromagnetic field or on an insulating body. This charge can flow as soon as a low-impedance path to ground is established. Static-sensitive units can be permanently damaged by static discharge potentials of as little as 40 volts. Charges carried by the human body, which can be thousands of times higher than this 40 V threshold, can accumulate through as simple a mechanism as walking across non-conducting floor coverings such as carpet or tile. These charges may be stored on clothing, especially when the ambient air is dry, through friction between the body and/or various clothing layers. Synthetic materials accumulate higher charges than natural fibers. Electrostatic voltage levels on insulators may be very high, in the order of thousands of volts.

Various electrical and electronic components are vulnerable to electrostatic discharge (ESD). These include discrete components, hybrid devices, integrated circuits (ICs), and printed circuit boards (PCBs) assembled with these devices.

13.2 Handling ESD-Sensitive Devices

ESD-sensitive devices must only be handled in static-controlled locations. Some recommendations for such handling practices follow:

- Handling areas must be equipped with a grounded table, floor mats, and wrist strap.
- A relative humidity level must be maintained between 20% and 80% non-condensing.
- No ESD-sensitive board or component should be removed from its protective package, except in a static-controlled location.
- A static-controlled environment and correct static-control procedures are required at both repair stations and maintenance areas.
- ESD-sensitive devices must be handled only after personnel have grounded themselves via wrist straps and mats.
- Boards or components should never come in contact with clothing, because normal grounding cannot dissipate static charges on fabrics.
- A circuit board must be placed into an anti-static plastic clamshell before being removed from the work location and must remain in the clamshell until it arrives at a static-controlled repair/test center.
- Circuit boards must not be changed or moved needlessly. Handles may be provided on circuit boards for use in their removal and replacement; care should be taken to avoid contact with the connectors and components.
- On-site repair of ESD-sensitive equipment should not be undertaken except to restore service in an emergency where spare boards are not available. Under these circumstances repair station techniques must be observed. Under normal circumstances a faulty or suspect circuit board must be sent to a repair center having complete facilities, or to the manufacturer for exchange or repair.

- Where protective measures have not been installed, a suitable alternative would be the use of a Portable Field Service Grounding Kit (for example, 3M Kit #8501 or #8507). This consists of a portable mat and wrist strap which must be attached to a suitable ground.
- A circuit board in a static-shielding bag or clamshell may be shipped or stored in a cardboard carton, but the carton must not enter a static-controlled area such as a grounded or dissipative bench top or repair zone. Do not place anything else inside the bag (for example, repair tags).
- Treat all PCBs and components as ESD sensitive. Assume that you will damage the PCB or component if you are not ESD conscious.
- Do not use torn or punctured static-shielding bags. A wire tag protruding through the bag could act as a "lightning rod", funneling the entire charge into the components inside the bag.
- Do not allow chargeable plastics, such as binders, within 0.6 m of unshielded PCBs.
- Do not allow a PCB to come within 0.3 m of a computer monitor.

13.3 Prime Static Accumulators

Table 5 provides some background information on static-accumulating materials.

Table 5: Static-Accumulating Materials

Work Surfaces	• formica (waxed or highly resistive) • finished wood • synthetic mats • writing materials, note pads, etc.
Floors	• wax-finished • vinyl
Clothes	• common cleanroom smocks • personal garments (all textiles) • non-conductive shoes
Chairs	• finished wood • vinyl • fiberglass
Packing and handling	• common polyethylene bags, wraps, envelopes, and bubble pack • pack foam • common plastic trays and tote boxes
Assembly, cleaning, and repair areas	• spray cleaners • common solder sucker • common soldering irons • common solvent brushes (synthetic bristles) • cleaning, drying and temperature chambers

13.4 Handling Printed Circuit Boards

ESD damage to unprotected sensitive devices may occur at any time. ESD events can occur far below the threshold of human sensitivity. Follow this sequence when it becomes necessary to install or remove a circuit board:

1. After you are connected to the grounded wrist strap, remove the circuit board from the frame and place it on a static-controlled surface (grounded floor or table mat).
2. Remove the replacement circuit board from the static-shielding bag or clamshell and insert it into the equipment.
3. Place the original board into the shielding bag or clamshell and seal it with a label.
4. Do not put repair tags inside the shielding bag or clamshell.
5. Disconnect the wrist strap.

Chapter 14 Acronyms

1PPS	One Pulse Per Second
2-D or 2D	Two Dimensional
3-D or 3D	Three Dimensional
AC	Alternating Current
A/D	Analog-to-Digital
ADC	Analog-to-Digital Convertor
ADR	Accumulated Doppler Range
ADR	Accumulated Delta Range
AGC	Automatic Gain Control
AK	Authentication Key
AL	Alarm Limit
AltBOC	Alternate Binary Offset Carrier
AMSAT	American Satellite
APC	Aircraft Power Conditioner
ARNS	Aeronautical Radio Navigation Services
ARP	Antenna Reference Point
AS	Anti-Spoofing
ASCII	American Standard Code for Information Interchange
ASIC	Application Specific Integrated Circuits
AVL	Automatic Vehicle Location
BCD	Binary Coded Decimal
BDE	Borland Database Engine
BDS	Black Diamond System
BFS	Broadband Fiber Source
BIH	Bureau l'International de l'Heure
BIST	Built-In Self-Test
BIT	Built-In Test
BNR	Binary Numerical Representation
BOC	Binary Offset Carrier
BPS	Bits per Second
BPSK	Bi-Phase Shift Key
BSG	Baseband Signal Generator
BTS	Conventional Terrestrial System (BIH defined)
BW	Bandwidth
C/A Code	Coarse/Acquisition Code
CAN	Controller Area Network
CASM	Coherent Adaptive Subcarrier Modulation
CBIT	Continuous Built In Test
cc	Cubic Centimeters
CCITT	Command, Control, and Intelligence Technical Test
CD	Clock Drift
CD	Compact Disc
cd	Change Directory
CDGPS	Canada-Wide Differential Global Positioning System
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CDU	Control and Display Unit

CE	Conformité Européenne
CEP	Circular Error Probable
CF	Compact Flash
CFGP	Configuration Parameters
CISPR	International Special Committee On Radio Interference
CKSC	Clock/Status Card
CL	Long Code
CLK	System Clock
CM	Moderate Length Code
CMG	Course Made Good
CMP	Comparator Message Processor
CMR	Compact Measurement Record
C/No	Post Correlation Carrier to Noise Ratio in dB-Hz
CoCom	Coordinating Committee on Multilateral Export Controls
COG	Course Over Ground
COGO	Coordinate Geometry
COSPAS	Cosmitscheskaja Sistema Poiska Awarinitsch Sudow *(Russian: space system for search of vessels in distress)*
CPLD	Complex Programmable Logic Device
CPU	Central Processing Unit
CR	Carriage Return
CRC	Cyclic Redundancy Check
CRR	Common Reference Receiver
CS	Commercial Service
CSA	Canada Shipping Act
CSIC	Coordination Scientific Information Center
CTP	Conventional Terrestrial Pole
CTS	Clear To Send
CTS	Conventional Terrestrial System
CW	Continuous Wave
dB	Decibel
dBm	Decibel Relative to 1 milliWatt
DC	Direct Current
DCD	Data Carrier Detected
DCE	Data Communications Equipment *(Modem)*
DCO	Digitally Controlled Oscillator
DDS	Direct Digital Sampling
DGNSS	Differential Global Navigation Satellite System
DGPS	Differential Global Positioning System
DHCP	Dynamic Host Configuration Protocol
DL	Data Logger
DLL	Delay Lock Loop
DoD	Department of Defence *(U.S.)*
DOP	Dilution Of Precision
DPB	Digital Pulse Blanking
DR	Dead Reckoning
DRAM	Dynamic Random Access Memory
DRMS	Distance Root Mean Square
DSP	Digital Signal Processor
DSR	Data Set Ready
DTE	Data Terminal Equipment
DTR	Data Terminal Ready

D/U	Desired/Undesired
e	Eccentricity
E-L	Early to Late
ECEF	Earth-Centred-Earth-Fixed
EDM	Electronic Distance Measuring *(instrument)*
EEPROM	Electrically Erasable Programmable Read Only Memory
EGNOS	European Geo-Stationary Navigation Overlay System
EIA	Electronic Industries Alliance
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Immunity
EP	Engineering Practice
ESA	European Space Agency
ESD	Electrostatic Discharge
ESN	Electronic Serial Number
FAA	Federal Aviation Administration
FCC	Federal Communication Commission
FDA	Frequency Distribution Amplifier
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FEPROM	Flash Erasable Programmable Read Only Memory
FIFO	First In, First Out
FKP	Flachen Korrectur Parameter (Plane Correction Parameter) *German*
FLL	Frequency Lock Loop
FMEA	Failure Mode Effects Analysis
FOC	Full Operational Capability
FOG	Fibre Optic Gyro
FOM	Figure of Merit
FPGA	Field-Programmable Gate Array
FR	Factory Reset
FTP	File Transfer Protocol
FTS	Frequency and Time Standard
FW	Firmware
GAGAN	GPS Aided GEO Augmented Navigation *(India)*
GaIn	Galileo Industries
GCC	Galileo Control Centre
GDOP	Geometric Dilution Of Precision
GEO	Geo-stationary Satellite
GIC	GPS Integrity Channel
GL	GLONASS *(NMEA talker ID)*
GLONASS	Global Navigation Satellite System
GM	Gauss-Markov
GMS	Ground Mission Segment
GMT	Greenwich Mean Time
GN	Combined GPS and GLONASS *(NMEA talker ID)*
GND	Ground
GNSS	Global Navigation Satellite System
G.P.	Ground Plane
GP	GPS *(NMEA talker ID)*
GPAI	General Purpose Analog Input
GPS	Global Positioning System
GRAS	Ground-based Regional Augmentation System *(Australia)*

GRC	Galileo Reception Chain
GRCN	Galileo Reception Chain Non-PRS
GSS	Galileo Sensor Stations
GSTB	Galileo System Test Bed
GTR	Galileo Test Receiver
GTS	Galileo Test Signal Generator
GUI	Graphical User Interface
GUS	Ground Uplink Station
GUST	WAAS GUS-Type 1
GUSTR	WAAS GUST Type-1 Receiver
HDOP	Horizontal Dilution Of Precision
hex	Hexadecimal
HFOM	Horizontal Figure of Merit
HMAC	Hashed Message Authentication Code
HP	High Performance *(standard OmniSTAR service)*
HTDOP	Horizontal Position and Time Dilution Of Precision
Hz	Hertz
I and Q	In-Phase and Quadrature *(Channels)*
I Channel	In-phase Data Channel
IBIT	Initiated Built In Test
IC	Integrated Circuit
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
ICP	Integrated Carrier Phase
ID	Identification
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical & Electronics Engineers
IERS	International Earth Rotation Service
IF	Intermediate Frequency
IGP	Ionospheric Grid Point
IGRF	International Geometric Reference Field
IGS CB	International GPS Service Central Bureau (IGS CB)
IM	Intermodulation
IMLA	Integrated Multipath Limiting Antenna
IMO	International Maritime Organization
IMU	Inertial Measuring Unit
INH	Inhibit
INS	Inertial Navigation System
I/O	Input/Output
IODE	Issue of Data (Ephemeris)
IOV	In-Orbit Validation
IP	Internet Protocol
IRQ	Interrupt Request
ISG	IF Signal Generator
ISO	International Organization for Standardization (*not an acronym but a short form*)
ITRF	International Terrestrial Reference System
JPL	Jet Propulsion Laboratory (*NASA*)
JTAG	Joint Test Action Group
KPA	Klystron Power Amplifier
Kb	Kilobit

KB	Kilobyte
KMF	Key Management Facility
L1	The 1575.42 MHz GPS carrier frequency including C/A and P-Code
L1C	Future GPS L1 civilian frequency
L1F	Future Galileo L1 civilian frequency
L2	The 1227.60 MHz 2nd GPS carrier frequency *(P Code only)*
L2C	The L2 civilian code transmitted at the L2 frequency *(1227.6 MHz)*
L5	The 1176.45 MHz 3rd civil GPS frequency that tracks carrier at low signal-to-noise ratios
LAAS	Local Area Augmentation System
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
LF	Line Feed
LGF	LAAS Ground Facility
LHCP	Left Hand Circular Polarization
LME	Line Maintenance Equipment
LNA	Low Noise Amplifier
LO	Local Oscillator
LRU	Line Replacement Unit
LSB	Least significant bit
LVTTL	Low Voltage Transistor Transistor Logic
MAC	Media Access Control *(Ethernet)*
MAT	Multipath Assessment Tool
Mb	Megabit
MB	Megabyte
mBOC	Multiplexed Binary Offset Carrier
MEDLL	Multipath Estimating Delay Lock Loop
MEO	Medium Earth Orbit
MET	Multipath Elimination Technology
MET	Meteorological
MGRS	Military Grid Reference System
MHz	MegaHertz
MIB	Management Information Base
MIL	Military
MINOS	Multiple Independent NOmadic Stargazer
MKI	Mark Input
MKMF	Mission Key Management Facility
MMCX	Multimedia Communications Exchange *(Lucent)*
MMT	Multipath Mitigation Technology
MOPS	Minimum Operational Performance Standard
MP	Message Processor
MPC	Modulated Precision Clock
MPM	Multipath Meter
ms	Millisecond
MSAS	MTSAT Satellite Based Augmentation System *(Japan)*
MSAT	Mobile Satellite
MSB	Most significant bit
MSL	Mean sea level
MSR	Measure Output
MTBF	Mean Time Between Failures
MTSAT	Multi-Functional Transport Satellite
N/A	Not Applicable

NAS	National Airspace System *(U.S.)*
NASA	National Aeronautics and Space Administration *(U.S.)*
NTS	National Topographic Series *(Canada)*
NAV	RINEX Ephemeris File
NAVSTAR	NAVigation Satellite Timing And Ranging *(synonymous with GPS)*
N/C *or* NC	Not Connected
NCC	Network Control Center *(OmniSTAR)*
NCO	Numerically Controlled Oscillator
ND	Navigation Data
NH	Neuman-Hoffman
NMEA	National Marine Electronics Association
N. mi.	Nautical mile
NOC	Network Operations Center
ns	Nanosecond
NVM	Non-Volatile Memory
OBS	RINEX Observation File
OCXO	Oven Controlled Crystal Oscillator
OEM	Original Equipment Manufacturer
OP	Operational Parameters
OS	Open Service
PAC	Pulsed Aperture Correlator
PC	Personal Computer
PC	Phase Centre
P-Code	Precise Code
PBIT	Power-Up Built-In Test
PCB	Printed Circuit Board
PCMCIA	Personal Computer Memory Card International Association
PDC	Power and Data Card
PDF	Power Distribution Function
PDF	Portable Document File
PDOP	Position Dilution Of Precision
PDP	Pseudorange/Delta-Phase
PE-90	Parameters of the Earth 1990 *(see PZ90)*
PIN	Position Indicator
PLL	Phase Lock Loop
PPM	Parts Per Million
PPP	Point to Point Protocol
PPS	Precise Positioning Service or Pulse Per Second
PRN#	PseudoRandom Noise Number
PRS	Public Regulated Service
PSN	Part Serial Number
PSR	Pseudorange
PV	Position Valid
PVT	Position Velocity Time
PZ90	Parametry Zemli 1990 *(see PE-90)*
Q Channel	Quadrature Data-Free Channel
RAM	Random Access Memory
RAS	Remote Access Service
RCC	Rescue Coordination Centre
RF	Radio Frequency

RFDC	Radio Frequency Direct Current
RFU	Radio Frequency Uplink
RHCP	Right Hand Circular Polarization
RI	Ring Indicator
RINEX	Receiver Independent Exchange Format
RLG	Ring Laser Gyro
RoHS	Restriction of the use of Hazardous Substances
RM	Raw Measurements
ROM	Read Only Memory
RMA	Return Material Authorization
RMS	Root Mean Square
RSS	Residual Solution Status
RTC	Real-Time Clock
RTCA	Radio Technical Commission for Aviation Services
RTCM	Radio Technical Commission for Maritime Services
RTCMV3	RTCM Version 3.0
RTK	Real Time Kinematic
RTS	Request To Send
RXD	Received Data
SA	SMART ANTENNA
SA	Selective Availability
SAE	Society of Automotive Engineers
SAR	Search and Rescue
SARSAT	Search and Rescue Satellite Aided Tracking
SBAS	Satellite Based Augmentation System
SC	Safety Computer
SCAT-I	Special Category I
SD	Standard Deviation
SEP	Spherical Error Probable
SG	Signal Generator
SGS-90	Soviet Geodetic System 1990
SI	Système Internationale
SigGen	WAAS GUS Type-1 Signal Generator
SiS	Signal in Space
SLIP	Serial Line Internet Protocol
SNAS	Satellite Navigation Augmentation System *(China)*
SNR	Signal-to-Noise Ratio
SOL	Safety-of-Life
SPS	Standard Position Service
sps	Symbols Per Second
SPAN	Synchronized Position Attitude Navigation
SQM	Signal Quality Monitoring
SRAM	Static Random Access Memory
SS II	SUPERSTAR II
SU	(former) Soviet Union *(now Russia)*
SV	Space Vehicle
SVID	Space Vehicle Identifier
SVN	Space Vehicle Number
SW	Software
SWRU	Software Replacement Unit
TCP	Transmission Control Protocol

TCXO	Temperature Compensated Crystal Oscillator
TDOP	Time Dilution Of Precision
TES	Time Estimator Status
TIL	Time Integrity Limit
TNM	Telecommunications Network Management
TOA	Time of Almanac
TOE	Time of Ephemeris
TOW	Time of Week
TRAIM	Time Receiver Autonomous Integrity Monitor
TTFF	Time-To-First-Fix
TTL	Transistor-Transistor Logic
TTNL	Time to Narrow Lane
TVS	Transient Voltage Suppressor
TXD	Transmitted Data
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
UDRE	User Differential Range Error
UHF	Ultra High Frequency
USB	Universal Serial Bus
USGS	United States Geological Survey
UTC	Coordinated Universal Time
UTC(SU)	Coordinated Universal Time *(former Soviet Union, now Russia)*
V AC	Volts Alternating Current
V DC	Volts Direct Current
VARF	Variable Frequency
VBS	Virtual Base Station *(standard OmniSTAR service)*
VCTCXO	Voltage Controlled Temperature Compensated Crystal Oscillator
VDOP	Vertical Dilution of Precision
VFD	Vacuum Fluorescent Display
VFOM	Vertical Figure of Merit
VSWR	Voltage Standing Wave Ratio
WAAS	Wide Area Augmentation System
WAAS G-II	WAAS Reference Receiver: G-II
WADGPS	Wide Area DGPS
WEEE	Waste Electrical and Electronic Equipment
WGS	World Geodetic System
WHQL	Windows Hardware Quality Lab *(Microsoft)*
WMP	WAAS Message Processor
WNA	Week number of almanac
WPT	Waypoint
XP	Extra Performance *(standard OmniSTAR service)*
XTE	Crosstrack Error
ZUPT	Zero Velocity Update

Chapter 15 Glossary

Acquisition The process of locking onto a satellite's C/A code and P-code. A receiver acquires all available satellites when it is first powered up, then acquires additional satellites as they become available and continues tracking them until they become unavailable.

Address Field For sentences in the NMEA standard, the fixed length field following the beginning sentence delimiter "$" (HEX 24). For NMEA approved sentences, composed of a two character talker identifier and a three character sentence formatter. For proprietary sentences, composed of the character "P" (HEX 50) followed by a three character manufacturer identification code.

ADR Accumulated Doppler Range. Carrier phase, in cycles.

Almanac A set of orbit parameters that allows calculation of approximate GPS satellite positions and velocities. The almanac is used by a GPS receiver to determine satellite visibility and as an aid during acquisition of GPS satellite signals.

Almanac Data A set of data which is downloaded from each satellite over the course of 12.5 minutes. It contains orbital parameter approximations for all satellites, GPS to universal standard time (UTC) conversion parameters, and single-frequency ionospheric model parameters.

Ambiguity The integer number of carrier cycles between a satellite and receiver.

Anti-Spoofing Denial of the P-code by the Control Segment is called Anti-Spoofing. It is normally replaced by encrypted Y-code, [see "P-Code" and "Y-Code"]

Antipodal Satellites Antipodal satellites are satellites in the same orbit plane separated by 180 degrees in argument of latitude.

ASCII A 7-bit wide serial code describing numbers, upper and lower case characters, special and non-printing characters. Typically used for textual data.

Attenuation Reduction of signal strength

Azimuth The horizontal direction of a celestial point from a terrestrial point, expressed as the angular distance from 000° (reference) clockwise through 360°. The reference point is generally True North, but may be Magnetic North, or Relative (ship's head).

Baseline
1) The line between a pair of stations for which simultaneous GPS data has been collected.
2) NovAtel's Waypoint Software: Connection between two stations with one or more sessions. Normally, a session and a baseline can be considered the same. However, in some cases there may be more than one session per baseline. This is called a duplicate session baseline, and it is plotted yellow on the screen.

Base Station The GPS receiver which is acting as the stationary reference. It has a known position and transmits messages for the rover receiver to use to calculate its position.

Bearing	The horizontal direction of one terrestrial point from another terrestrial point, expressed as the angular distance from a reference direction, usually measured from 000° at the reference direction clockwise through 360°. The reference point may be True North, Magnetic North, or Relative (ship's head).
Broadcast Ephemerides	A set of parameters which describe the location of satellites with respect to time, and which are transmitted (broadcast) from the satellites.
Canada-Wide Differential Global Positioning System (CDGPS)	The CDGPS system is a free Canada-wide DGPS service that is accessible coast-to-coast, throughout most of the continental United States, and into the Arctic. See also *Section 4.1.2, Canada/America-Wide CDGPS* starting on *Page 25* for more information.
Carrier	The steady transmitted RF signal whose amplitude, frequency, or phase may be modulated to carry information.
Carrier Phase Ambiguity	The number of integer carrier phase cycles between the user and the satellite at the start of tracking. (Sometimes ambiguity for short).
Carrier Phase Measurements	These are “Accumulated Doppler Range” (ADR) measurements. They contain the instantaneous phase of the signal (modulo 1 cycle) plus some arbitrary number of integer cycles. Once the receiver is tracking the satellite, the integer number of cycles correctly accumulates the change in range seen by the receiver. When a “lock break” occurs, this accumulated value can jump an arbitrary integer number of cycles (this is called a cycle slip).
C-Band	C Band is the original frequency allocation for communications satellites. C-Band uses 3.7-4.2 GHz for downlink and 5.925-6.425 Ghz for uplink.
Check Point	NovAtel’s Waypoint Software: A station with known coordinates, but these coordinates are only used as a check against GrafNet’s computed coordinates.
Checksum	By NMEA standard, a validity check performed on the data contained in the sentences, calculated by the talker, appended to the message, then recalculated by the listener for comparison to determine if the message was received correctly. Required for some sentences, optional for all others.
Circular Error Probable (CEP)	Circular error probable; the radius of a circle such that 50% of a set of events occur inside the boundary.
Coarse Acquisition (C/A) Code	A pseudorandom string of bits that is used primarily by commercial GPS receivers to determine the range to the transmitting GPS satellite. The 1023 chip C/A code repeats every 1 ms giving a code chip length of 300 m which, is very easy to lock onto.
Communication Protocol	A method established for message transfer between a talker and a listener which includes the message format and the sequence in which the messages are to be transferred. Also includes the signalling requirements such as bit rate, stop bits, parity, and bits per character.
Control Point	See *Ground Control Point (GRP)*
Control Segment	The Master Control Station and the globally dispersed Reference Stations used to manage the GPS satellites, determine their precise orbital parameters, and synchronize their clocks.

Controller Area Network Bus (CAN Bus)	A rugged serial bus with a protocol that provides services for processes, data and network management.
Coordinated Universal Time	This time system uses the second-defined true angular rotation of the Earth measured as if the Earth rotated about its Conventional Terrestrial Pole. However, UTC is adjusted only in increments of one second. The time zone of UTC is that of Greenwich Mean Time (GMT).
Course	The horizontal direction in which a vessel is to be steered or is being steered; the direction of travel through the air or water. Expressed as angular distance from reference North (either true, magnetic, compass, or grid), usually 000° (north), clockwise through 360°. Strictly, the term applies to direction through the air or water, not the direction intended to be made good over the ground [see *"Track Made Good"*]. Differs from heading.
Course Made Good (CMG)	The single resultant direction from a given point of departure to a subsequent position; the direction of the net movement from one point to the other. This often varies from the track caused by inaccuracies in steering, currents, cross-winds, etc. This term is often considered to be synonymous with Track Made Good, however, Course Made Good is the more correct term.
Course Over Ground (COG)	The actual path of a vessel with respect to the Earth (a misnomer in that courses are directions steered or intended to be steered through the water with respect to a reference meridian); this will not be a straight line if the vessel's heading yaws back and forth across the course.
Cross Track Error (XTE)	The distance from the vessel's present position to the closest point on a great (XTE) Circle line connecting the current waypoint coordinates. If a track offset has been specified in the receiver SETNAV command, the cross track error will be relative to the offset track great circle line.
Cycle Slip	When the carrier phase measurement jumps by an arbitrary number of integer cycles. It is generally caused by a break in the signal tracking due to shading or some similar occurrence.
Dead Reckoning	The process of determining a vessel's approximate position by applying (DR) from its last known position a vector or a series of consecutive vectors representing the run that has since been made, using only the courses being steered, and the distance run as determined by log, engine rpm, or calculations from speed measurements.
Destination	The immediate geographic point of interest to which a vessel is navigating. It may be the next waypoint along a route of waypoints or the final destination of a voyage.
Differential GPS (DGPS)	A technique to improve GPS accuracy that uses pseudorange errors at a known location to improve the measurements made by other GPS receivers within the same general geographic area.

Dilution of Precision (DOP) A numerical value expressing the confidence factor of the position solution based on current satellite geometry. The lower the value, the greater the confidence in the solution. DOP can be expressed in the following forms.

GDOP:	Uncertainty of all parameters (latitude, longitude, height, clock offset)
PDOP:	Uncertainty of 3-D parameters (latitude, longitude, height)
HTDOP:	Uncertainty of 2-D and time parameters (latitude, longitude, time)
HDOP:	Uncertainty of 2-D parameters (latitude, longitude)
VDOP:	Uncertainty of height parameter
TDOP:	Uncertainty of clock offset parameter

Doppler The change in frequency of sound, light, or other wave caused by movement of its source relative to the observer.

Theoretical Doppler:	The expected Doppler frequency based on a satellite's motion relative to the receiver. It is computed using the satellite's coordinates and velocity, and the receiver's coordinates and velocity.
Apparent Doppler:	Same as Theoretical Doppler of satellite above, with clock drift correction added.
Instantaneous Carrier Doppler Frequency	The Doppler frequency measured at the receiver, at that epoch.

Doppler Aiding A signal processing strategy, which uses a measured Doppler shift to help a receiver smoothly track the GPS signal, to allow more precise velocity and position measurement.

Double-Difference A mathematical technique comparing observations by differencing between receiver channels and then between the base and rover receivers.

Double-Difference Carrier Phase Ambiguity Carrier phase ambiguities which are differenced between receiver channels Carrier Phase and between the base and rover receivers. They are estimated when Ambiguitya double-difference mechanism is used for carrier phase positioning. (Sometimes double-difference ambiguity or ambiguity, for short).

Earth-Centred-Earth-Fixed (ECEF) This is a coordinate-ordinate system which has the X-coordinate in the Earth's equatorial plane pointing to the Greenwich prime meridian, the Z-axis pointing to the north pole, and the Y-axis in the equatorial plane 90° from the X-axis with an orientation which forms a right-handed XYZ system.

Eccentricity (e) A dimensionless measurement defined for a conic section where e= 0 is a circle, e = 1 is an ellipse, 0 < e < 1 is a parabola and e > 1 is a hyperbola. The eccentricity of GPS is nominally 1.02.

Elevation The angle from the horizon to the observed position of a satellite.

Ellipsoid A smooth mathematical surface which represents the Earth’s shape and very closely approximates the geoid. It is used as a reference surface for geodetic surveys.

Ellipsoidal Height	Height above a defined ellipsoid approximating the surface of the Earth.
Ephemeris	A set of satellite orbit parameters that are used by a GPS receiver to calculate precise GPS satellite positions and velocities. The ephemeris is used in the determination of the navigation solution and is updated periodically by the satellite to maintain the accuracy of GPS receivers.
Ephemeris Data	The data downlinked by a GPS satellite describing its own orbital position with respect to time.
Epoch	Strictly a specific point in time. Typically when an observation is made.
Field	A character or string of characters immediately preceded by a field delimiter.
Figure of Merit	NovAtel SUPERSTAR II-based L1 receivers provide an estimated accuracy level. The accuracy level estimate is provided in the horizontal and vertical Figure of Merit (FOM). The FOM reflects a 95% confidence level for the position solution accuracy estimate. The FOM accounts for all major sources of errors in the pseudoranges of the satellites used in the position solution. The error sources which are included are ionospheric and tropospheric errors, satellite position errors based on transmitted user range error, and thermal noise.
Fixed Ambiguity Estimates	Carrier phase ambiguity estimates which are set to a given number and held constant. Usually they are set to integers or values derived from linear combinations of integers.
Fixed Discrete Ambiguity Estimates	Carrier phase ambiguities which are set to values that are members of a predetermined set of discrete possibilities, and then held constant.
Fixed Field	A field in which the number of characters is fixed, including the cyclic redundancy check (CRC) field.
Fixed Integer Ambiguity Estimates	Carrier phase ambiguities which are set to integer values and then held constant.
Flash ROM	Programmable read-only memory.
Galileo	Galileo will be the Europe Union's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. The fully deployed Galileo system will consist of 30 satellites (27 operational + 3 active spares), positioned in three circular orbits, 23616 km above the Earth, and at an inclination of the orbital planes of 56 degrees with reference to the equatorial plane. See also *Chapter 6, Galileo* starting on *Page 36*.
Galileo Industries (GaIn)	GaIn is a consortium of European prime companies charged with the development of the Galileo system for the European Space Agency.
Geometric Dilution of Precision (GDOP)	[See *"Dilution of Precision (DOP)"*]
Geoid	The shape of the Earth if it were considered as a sea level surface extended continuously through the continents. The geoid is an equipotential surface coincident with mean sea level to which at every point the plumb line (direction in which gravity acts) is perpendicular. The geoid, affected by local gravity disturbances, has an irregular shape.

Geodetic Datum The reference ellipsoid surface that defines the coordinate system.

Geo-stationary A satellite orbit along the equator that results in a constant fixed position over a particular reference point on the Earth's surface. (GPS satellites are not geo-stationary.)

Global Navigation Satellite System (GLONASS) GLONASS is a radio satellite navigation system, the Russian counterpart to the United States' GPS and the European Union's Galileo positioning systems. When complete, the GLONASS space segment will consist of 24 satellites in three orbital planes, with eight satellites per plane in three orbital planes. The satellites are placed into nominally circular orbits with target inclinations of 64.8 degrees and an orbital height of about 19,140 km, which is about 1,050 km lower than GPS satellites. See also *Chapter 5, GLONASS Overview* starting on *Page 29*.

Global Positioning System (GPS) Full name is NAVSTAR Global Positioning System. A space-based radio positioning system which provides suitably equipped users with accurate position, velocity and time data. GPS provides this data free of direct user charge worldwide, continuously, and under all weather conditions. The GPS constellation consists of 24 orbiting satellites, four equally spaced around each of six different orbital planes. The system is being developed by the Department of Defence under U.S. Air Force management. See also *Chapter 1, GPS Overview* starting on *Page 9*.

Great Circle The shortest distance between any two points along the surface of a sphere or ellipsoid, and therefore the shortest navigation distance between any two points on the Earth. Also called Geodesic Line.

Ground Control Point (GRP) NovAtel's Waypoint Software: A reference station with known latitude, longitude and height coordinates. The user may also assign horizontal and vertical standard deviations for these values. There can be horizontal, vertical or 3-D points, and there must always be at least one 3-D point or else one horizontal and one vertical point per project.

Handshaking Predetermined hardware or software activity designed to establish or maintain two machines or programs in synchronization. Handshaking concerns the exchange of messages or packets of data between two systems with limited buffers. Hardware handshaking uses voltage levels or pulses in wires to carry the handshaking signals. Software handshaking uses data units (for example, binary bits) carried by some underlying communication medium.

Heading The direction in which a vessel points or heads at any instant, expressed in degrees 000° clockwise through 360° and may be referenced to True North, Magnetic North, or Grid North. The heading of a vessel is also called the ship's head. Heading is a constantly changing value as the vessel oscillates or yaws across the course due to the effects of the air or sea, cross currents, and steering errors.

Horizontal Dilution of Precision (HDOP) [See *"Dilution of Precision (DOP)"*]

Horizontal and Time Dilution of Precision (HTDOP) [See *"Dilution of Precision (DOP)"*]

Integer Ambiguity Estimates Carrier phase ambiguity estimates which are only allowed to take on integer values.

Iono-Free Carrier Phase Observation	A linear combination of L1 and L2 carrier phase measurements which provides an estimate of the carrier phase observation on one frequency with the effects of the ionosphere removed. It provides a different ambiguity value (non-integer) than a simple measurement on that frequency.
Kinematic	The user's GPS antenna is moving. In GPS, this term is typically used with precise carrier phase positioning, and the term dynamic is used with pseudorange positioning.
L-band	L-band is a frequency range between 390 MHz and 1.55 GHz which is used for satellite communications and for terrestrial communications between satellite equipment. L-band includes the GPS carrier frequencies L1, L2, CDGPS and the OmniSTAR satellite broadcast signal. See also *Chapter 4, L-band Positioning* starting on *Page 23*.
L1 Frequency	The 1575.42 MHz GPS carrier frequency, which contains the course acquisition (C/A) code, as well as encrypted P-code, and navigation messages used by commercial GPS receivers. See also *Chapter 1, GPS Overview* starting on *Page 9*.
L2 Frequency	The 1227.60 MHz secondary GPS carrier frequency, containing only encrypted P-code, used primarily to calculate signal delays caused by the ionosphere. Currently, GPS satellites transmit the civilian C/A code on the L1 frequency, and the military P(Y) code on both the L1 and L2 frequencies. New Block IIR-M GPS satellites will transmit the same signals as previous GPS satellites, but will also have a new signal, called L2C, on the L2 frequency. See also *Chapter 1, GPS Overview* starting on *Page 9* and *Chapter 7, L2C Overview* starting on *Page 39*.
L5 Frequency	The third civil GPS frequency at 1176.45 MHz beginning with the first Block IIF NAVSTAR GPS satellite to be launched in 2007. This frequency is located within the 960-1215 MHz frequency band. The L5 signal is equally split between an in-phase (I) data channel and a quadrature (Q) data-free channel, which improves resistance to interference, especially from pulse emitting systems in the same band as L5. See also *Chapter 8, L5 Overview* starting on *Page 40*.
Lane	A particular discrete ambiguity value on one carrier phase range measurement or double-difference carrier phase observation. The type of measurement is not specified (L1, L2, L1-L2, iono-free).
Local Observation Set	An observation set, as described on *Page 74*, taken by the receiver on which the software is operating.
Local Tangent Plane	A coordinate system based on a plane tangent to the ellipsoid's surface at the Plane user's location. The three coordinates are east, north and up. Latitude, longitude and height positions operate in this coordinate system.
Low-Latency Solution	A position solution which is based on a prediction. A model (based on previous base station observations) is used to estimate what the observations will be at a given time epoch. These estimated base station observations are combined with actual measurements taken at the rover station to provide a position solution.
Magnetic Bearing	Bearing relative to magnetic north; compass bearing corrected for deviation.
Magnetic Heading	Heading relative to magnetic north.

Magnetic Variation	The angle between the magnetic and geographic meridians at any place, expressed in degrees and minutes east or west to indicate the direction of magnetic north from true north.
Mask Angle	The minimum GPS satellite elevation angle permitted by a particular receiver design. Satellites below this angle will not be used in position solution.
Matched Observation Set Pair	Observations from both the base station and the local receiver which have been matched by time epoch, contain the same satellites, and are corrected for any known offsets.
Measurement Error Variance	The square of the standard deviation of a measurement quantity. The standard deviation is representative of the error typically expected in a measured value of that quantity.
Measurement Time Epoch	The point in time at which a receiver takes a measurement.
Misclosure	The gap between a receiver's computed and actual position.
Multipath Errors	GNSS positioning errors caused by the interaction of the satellite signal and its reflections.
Nanosecond	1×10^{-9} second.
Non-Volatile Memory	A type of memory device that retains data in the absence of a power supply.
Null Field	By NMEA standard, indicates that data is not available for the field. Indicated by two ASCII commas, for example, ",," (HEX 2C2C), or, for the last data field in a sentence, one comma followed by either the checksum delimiter "*" (HEX 2A) or the sentence delimiters <CR><LF> (HEX 0D0A). [Note: the ASCII Null character (HEX 00) is not to be used for null fields.]
Obscuration	Term used to describe periods of time when a GNSS receiver's line-of-sight to GNSS satellites is blocked by natural or man-made objects.
Observation	1) Any measurement. 2) NovAtel's Waypoint Software: Raw measurement file collected from a receiver that is set up over a stationary point. GrafNet only accepts GPB files. Other formats must be converted first. See the *GrafNav/Grafnet User Guide* for supported formats. GrafNet also requires single frequency carrier phase data as a minimum, and accepts dual frequency if available. Users wishing to perform code-only processing should use GrafNav.
Observation Set	A set of receiver measurements taken at a given time which includes one time for all measurements, and the following for each satellite tracked: PRN number, pseudorange or carrier phase or both, lock time count, signal strength, and tracking status. Only L1 measurements are included in the set. The observation set is assumed to contain information indicating how many satellites it contains and which ones have L1-only and which ones have L1/L1 pairs.

OmniSTAR	A wide-area GPS correction service, using L-band satellite broadcast frequencies (1525 - 1560 MHz). Data from many widely-spaced Reference Stations is used in a proprietary multi-site solution. OmniSTAR Virtual Base Station (VBS) types achieve sub-meter positioning over most land areas worldwide while OmniSTAR High Performance (HP) types achieve 10 cm accuracy. Use of the OmniSTAR service requires a subscription.
Origin Waypoint	The starting point of the present navigation leg, expressed in latitude and longitude.
Parallel Receiver	A receiver that monitors four or more satellites simultaneously with independent channels.
Parity	The even or odd quality of the number of ones or zeroes in a binary code. Parity is often used to determine the integrity of data especially after transmission.
Perigee	The point in a body's orbit at which it is nearest the Earth.
P-Code	Precise code or protected code. A pseudorandom string of bits that is used by GPS receivers to determine the range to the transmitting GPS satellite. P-code is replaced by an encrypted Y-code when Anti-Spoofing is active. Y-code is intended to be available only to authorized (primarily military) users. [See "Anti-Spoofing" , "(C/A) Code" and "Y-Code"]
PDOP	Position Dilution of Precision [See "Dilution of Precision (DOP)"]
Precise Positioning Service (PPS)	The GPS positioning, velocity, and time service which is available on a continuous, worldwide basis to users authorized by the U.S. Department of Defence (typically using P-code).
PRN Number	A number assigned by the GPS system designers to a given set of pseudorandom codes. Typically, a particular satellite will keep its PRN (and hence its code assignment) indefinitely, or at least for a long period of time. It is commonly used as a way to label a particular satellite.
Pseudolite	An Earth-based transmitter designed to mimic a satellite.
Pseudorange	The calculated range from the GPS receiver to the satellite determined by taking the difference between the measured satellite transmit time and the receiver time of measurement, and multiplying by the speed of light. Contains several sources of error.
Pseudorange Measurements	Measurements made using one of the pseudorandom codes on the GPS signals. They provide an unambiguous measure of the range to the satellite including the effect of the satellite and user clock biases.
PZ-90	Parametri Zemli 1990 (PZ-90, or in English translation, Parameters of the Earth 1990, PE-90) geodetic datum. GLONASS information is referenced to the PZ-90 geodetic datum, and GLONASS coordinates are reconciled in GLONASS-capable NovAtel receivers through a position filter and output to WGS84.
Receiver Channels	A GPS receiver specification which indicates the number of independent hardware signal processing channels included in the receiver design.

Reference Satellite	In a double-difference implementation, measurements are differenced between different satellites on one receiver in order to cancel the correlated errors. Usually one satellite is chosen as the “reference”, and all others are differenced with it.
Reference Station	See *“Base Station”*
Relative Bearing	Bearing relative to heading or to the vessel.
Remote Station	See *“Rover Station”*
Residual	In the context of measurement, the residual is the misclosure between the calculated measurements, using the position solution and actual measurements.
Root Mean Square (RMS)	A probability level of 68%.
Route	A planned course of travel, usually composed of more than one navigation leg.
Rover Station	The GPS receiver which does not know its position and needs to receive measurements from a base station to calculate differential GPS positions. (The terms remote and rover are interchangeable.)
RT-20	NovAtel’s Double-Differencing Technology for real-time kinematic (RTK) carrier phase floating ambiguity resolution.
Radio Technical Commission for Aeronautics (RTCA)	An organization which developed and defined a message format for differential positioning.
Radio Technical Commission for Maritime Services (RTCM)	An organization which developed and defined the SC-104 message format for differential positioning.
Real-Time Kinematic (RTK)	A type of differential positioning based on observations of carrier phase. In NovAtel documents it is also used with reference to RT-2 and RT-20.
SafeTrak	The receiver tracks a satellite by replicating the satellite's PRN code and aligning it with the received PRN code. A cross-correlation check is performed to check alignment and the cross-correlation channel shifts its code phase repeatedly to measure the power. If necessary, the tracking channel re-acquires the satellite to remove the cross-correlation error.
Satellite-Based Augmentation System (SBAS)	A type of geo-stationary satellite system that improves the accuracy, integrity, and availability of the basic GPS signals. This includes WAAS, EGNOS, and MSAS. See also *Chapter 3, Satellite-Based Augmentation System* starting on *Page 20*.
Selective Availability (SA)	The method used in the past by the United States Department of Defence to control access to the full accuracy achievable by civilian GPS equipment (generally by introducing timing and ephemeris errors).
Selected Waypoint	The waypoint currently selected to be the point toward which the vessel is travelling. Also called "to" waypoint, destination or destination waypoint.

Sequential Receiver A GPS receiver in which the number of satellite signals to be tracked exceeds the number of available hardware channels. Sequential receivers periodically reassign hardware channels to particular satellite signals in a predetermined sequence.

Session NovAtel's Waypoint Software: Concurrent period of time between two observation files at two different stations. One of the two stations will be the remote, and the other will be the master. The arrow on the screen will be pointing from the master to the remote. The direction is determined by GrafNet in order to form loop closures as well as to minimize the number of legs from a control point. Each session will be processed individually and combined in either a network adjustment or traverse solution. A session can have different statuses and colors depending on whether certain tests passed or failed.

Sidereal Day A sidereal day is the rotation period of the Earth relative to the equinox and is equal to one calendar day (the mean solar day) minus approximately four minutes.

Signal Quality Monitoring (SQM) Signal Quality Monitoring (SQM) technology is used to monitor GNSS and GEO signals in space for anomalous behavior.

Spherical Error Probable (SEP) The radius of a sphere, centred at the user's true location, that contains 50 percent of the individual three-dimensional position measurements made using a particular navigation system.

Spheroid Sometimes known as ellipsoid; a perfect mathematical figure which very closely approximates the geoid. Used as a surface of reference for geodetic surveys.

Standard Positioning Service (SPS) A positioning service made available by the United States Department of Defence which is available to all GPS civilian users on a continuous, worldwide basis (typically using C/A Code).

Space Vehicle ID (SV) Sometimes used as SVID. A unique number assigned to each satellite for identification purposes. The 'space vehicle' is a GPS satellite.

TDOP Time Dilution of Precision [See "Dilution of Precision (DOP)"]

Three-Dimensional Coverage (hours) The number of hours per day when four or more satellites are available with acceptable positioning geometry. Four visible satellites are required to determine location and altitude.

Three-Dimensional (3D) Navigation Navigation mode in which altitude and horizontal position are determined from satellite range measurements.

Tie Point NovAtel's Waypoint Software: Such a point may also be called a loop tie closure and is formed when two or more sessions "point" to it. Thus, there is a redundant determination at this point.

Time-To-First-Fix (TTFF) The actual time required by a GPS receiver to achieve a position solution. This specification will vary with the operating state of the receiver, the length of time since the last position fix, the location of the last fix, and the specific receiver design.

Track Made Good The single resultant direction from a point of departure to a point of arrival or subsequent position at any given time; may be considered synonymous with *Course Made Good*.

Traverse Station	NovAtel's Waypoint Software: This is a point with no tie or control information. It might have two stations connected to it, but one is pointing to it and the other is pointing from it.
True Bearing	Bearing relative to true north; compass bearing corrected for compass error.
True Heading	Heading relative to true north.
Two-Dimensional (2D) Coverage	The number of hours-per-day with three or more satellites visible. Three visible satellites can be used to determine location if the GPS receiver is designed to accept an external altitude input.
Two-Dimensional Navigation	Navigation mode in which a fixed value of altitude is used for one or more position calculations while horizontal (2D) position can vary freely based on satellite range measurements.
Undulation	The distance of the geoid above (positive) or below (negative) the mathematical reference ellipsoid (spheroid). Also known as geoidal separation, geoidal undulation, geoidal height.
Update Rate	The GPS receiver specification which indicates the solution rate provided by the receiver when operating normally.
UTC	[See "Coordinated Universal Time"]
VDOP	Vertical Dilution of Precision [See "Dilution of Precision (DOP)"]
Variable Field	By NMEA standards, a data field which may or may not contain a decimal point and which may vary in precision following the decimal point depending on the requirements and the accuracy of the measuring device.
Waypoint	A reference point on a track.
Wide Lane	A particular integer ambiguity value on one carrier phase range measurement or double-difference carrier phase observation when the difference of the L1 and L2 measurements is used. It is a carrier phase observable formed by subtracting L2 from L1 carrier phase data: $\Phi' = \Phi_1 - \Phi_2$. The corresponding wavelength is 86.2 cm.
World Geodetic System 1984 (WGS84)	An ellipsoid designed to fit the shape of the entire Earth as well as possible with a single ellipsoid. It is often used as a reference on a worldwide basis, while other ellipsoids are used locally to provide a better fit to the Earth in a local region. GPS uses the centre of the WGS84 ellipsoid as the centre of the GPS ECEF reference frame.
Y-Code	An encrypted form of P-code. Satellites transmit Y-Code in replace of P-code when Anti-Spoofing is in effect. [See "P-Code" and "Anti-Spoofing"]

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